Demanding on Many Dimensions

Validating the Interactivity-As-Demand Measurement Model for VR-Based Video Games

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Video games represent exemplar interactive experiences, and this direct user control over the form and content of on-screen information is one of many reasons that games are such enjoyable and meaningful experiences for players. However, interactivity also requires players to serve as co-authors of the experience, which brings with it certain demands on player’s limited attentional resources. Previous research has found evidence for at least four such demands: cognitive, emotional, physical (subdivided into controller intuitiveness and physical exertional) and social demands. Taken together, this five-factor structure is presented as the interactivity-as-demand model and has been used in a variety of cross-cultural contexts (among English-, German-, and Mandarin Chinese-speaking populations). These five dimensions explain unique variance in focal interactive user experiences but have yet to be applied to VR-based applications such as VR-based video games. Results on N = 144 VR video gamers confirmed the a priori factor structure of the Video Game Demand Scale (VDGS) held when applied to VR-based video games. More importantly, discrete VGDS dimensions predicted relevant VR outcomes: spatial presence was higher when VR controls were more intuitive (less demanding) and social presence was higher when experiences were more emotionally socially demanding. Likely due to the centrality of natural user interfaces and broader body movement in VR games, perceptions of physical demand (both controller demand and physical exertion) played a more central role on several entertainment outcomes. Non-gaming and social VR use was rare, hindering broader comparisons.

Keywords: virtual reality, interactivity, scale development, user experience, perceived demands

Video games provide for direct user control over the form and content of on-screen information (Steuer, 1992), resulting in enjoyable and meaningful experiences for players (Oliver et al., 2016). However, interactivity also constantly requires players to serve as co-authors of their experience (Wellenreiter, 2015), persistently demanding their limited cognitive resources (Fisher et al., 2018). Bowman et al. (2018) found evidence for four such demands: cognitive, emotional, physical (subdivided into controller intuitiveness and physical exertional) and social demands, each with unique impacts on players’ experiences.

The current study expands the scope of this interactivity-as-demand model to VR-based video games, given that VR systems might make more salient some demands over others (Bowman et al., 2021b; Harris et al., 2020). For example, VR systems are designed to embody the user’s sensory inputs to varying degrees (Biocca, 1997) and are well-suited for facilitating a sense of presence (Lombard & Ditton, 1997; Tamborini & Skalski, 2006) that is key to various entertainment (Hartmann & Fox, 2021) and persuasive outcomes (Ahn, 2015; Ahn et al., 2016). As an initial step towards understanding the perceived demands of VR-based video games, we report on the validity of the Video Game Demand Scale (VDGS) applied to VR gaming.

Interactivity as Demand

Interactivity is a core driver of the appeal of video games, yet it also brings with it both implicit and explicit requirements for (or demands on) the player’s input and their cognitive resources. From the interactivity-as-demand model (Bowman, 2018, 2021a), these demands can be felt in at least four broad categories: cognitive, emotional, physical (further subdivided into controller intuitiveness and exertional demands) and social.

Cognitive demands. Cognitive demands include the requirement for players to rationalize the on-screen challenges. Video games require players to actively assess and negotiate outcomes within their systems (Juul, 2011), sorting through the action affordances offered in the gameworld (Eden et al., 2018). To
make sense of and make decisions within the video game, players are constantly constructing durable-yet-flexible mental models of gameplay (McGloin et al., 2018). Cognitive skills are also included here, as video games place a premium on cognitive systems such as those tethered to visual attention and executive functioning (Green, 2018). Here, players must quickly process ever-changing on-screen content so it can be understood and acted on (Hodent, 2013).

**Emotional demands.** Emotional demands include players’ affective reactions while gaming, encompassing both bottom-up (subconscious and prival) and top-down (cognitive and deliberative) emotional reactions (see review in Hemenover & Bowman, 2018). Gaming content has evolved through the years to encourage both hedonic and eudaimonic reactions to gameplay (Daneels et al., 2021; Oliver et al., 2015), even within the same video game (Rogers et al., 2016) or gaming session (Holl et al., 2020). The gamut of emotions possible through video games was captured by Schell (2013), who explained that whereas games traditionally focused more on “below the neck” verbs such as running and jumping (more aligned with hedonic enjoyment), the medium has evolved to also consider “above the neck” verbs such as taking and listening (more aligned with eudaimonic appreciation).

**Physical demands.** Physical demands include the various input systems that players must engage to control on-screen action. These demands fall into two discrete categories: a focus on players’ handling of the controllers themselves and the amount of physical exertion during any given gaming session. Controller demands are related to how controllers are perceived by players as intuitive for gameplay, either because they are naturally mapped (adapted to the human perceptual system: Biocca, 1997; Skalski et al., 2011) or perceived as more intuitive by players (Liebold et al., 2020; Rogers et al., 2015). Exertional demands are aligned with more holistic energy expenditure especially relevant for games that emphasize haptic or motion input (Skalski et al., 2011). For example, exergames that make use of the whole body as a controller are successful at increasing energy expenditure (Sween et al., 2014).

**Social demands.** Social demands include the ways in which video games trigger within the player implicit or explicit responses to the presence of other social actors (both human and non-human; Banks & Carr, 2019). Video games can be deeply social experiences, as reflected in arcades (Egli & Meyers, 1984), tandem play (single-player games, played in social groups; Consalvo, 2017), and online gaming communities (Steinkuehler & Williams 2006). Social interaction is often involved as a core motivation for gameplay (Sherry et al., 2006; Yee, 2006). Elson et al. (2014) argued that social interactions in and around gaming can be as relevant to the overall experience as the on-screen gaming content itself.

**VR Gaming and Demand Perceptions**

Assessing how players perceive these different demands is useful for better understanding the overall experience of video gaming. For example, perceived demands predict self-report effort expenditure in discrete ways (e.g., cognitive demands predictive of mental effort; physical demands predictive of physical effort). Entertainment outcomes are also correlated with demand perceptions (e.g., emotional demands correlate with appreciation for and ratings of game narratives; controller demands correlate with enjoyment for and ratings of game controls; see Bowman et al., 2018; 2021a; Koban & Bowman, 2021). Likewise, systems that are too demanding can result in players reallocating attention to secondary tasks that are less useful (and perhaps, even detrimental) to in-game performance (Bowman et al., 2021b).

Of specific relevance to the current study is extending this research into VR-based video games, given that those games afford unique ways in which players can be engaged. For example, Bowman et al. (under review) found that increasing the playable field-of-view in a VR game increased people’s perceived cognitive and exertional demands of that game, with this increase in cognitive demand having a positive impact on enjoyment. Similar results have been found in research on 360-degree films. For example, Pressgrove & Bowman (2021) found that using head-mounted display (HMD) for 360-degree short films increased the cognitive and physical demand perceptions (as compared to the same content on a flat screen or an interactive screen). Likewise, Barreda-Ángeles et al. (2021) found that viewers experienced increased cognitive load when using HMDs for viewing news stories.

With respect to emotional demands, one suggestion is that VR environments increase empathy by more deeply involving users in the digital content—for example, fostering empathy by sharing the lived experiences of others (Ahn et al., 2013; Herrera et al., 2018). Likewise, VR games situate audiences as themselves directly encountering the events unfolding, which can enhance emotional demands. Studies on VR-based horror games find intense fear reactions (Lin, 2020), attributing these effects to the temporal salience of a plausibility illusion—that players felt as if they could be attacked because “unlike traditional media, players in a VR horror game must actively decide how they will react to such threats and manage to survive” (Lin, 2017, p. 351). Some have suggested that ratings systems for VR-based video games might need to be recalibrated to consider the more intense experiences they provide to players (Wilson & McGill, 2018).

VR-based video games might also have unique physical demands. Bowman et al. (under review) found that dancing video games were even more demanding when played in a fully functional field-of-view (even when compared to the same video game with only a forward-looking playfield), owing to the full range of motion required by 360-degree VR game. Wehden et al. (2021) found that using omnidirectional treadmills to play VR video games increased exertional demands, without impacting cybersickness (feelings of dizziness and disorientation that can accompany VR experiences). The use of omnidirectional treadmills also relates to the natural mapping elements of controller demands, insofar as the interface is designed to take advantage of natural user locomotion. However, these systems often fail to meet user expectations or, at least, are often less effective at gameplay than abstract but familiar game controllers (Liebold et al., 2020; Rogers et al., 2015).

Social demands in VR could be less relevant insofar as many VR systems are focused on immersing individuals into digital...
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The task load index from Hart and Staveland (1988, NASA-TLX) was used in the current study, a five-item scale ranging from “1 = very low” to “9 = very high” (M = 4.70, SD = 1.72, ω = .647). Scale modifications were made to apply the scale to video games, as in prior work (Bowman & Tamborini, 2015).

Validation items for predictive validity. We presumed that VR games perceived as more demanding would result in greater effort expenditure on each relevant dimension. To test this, we used Paas’ (1992) metric of effort expenditure, which includes four single item, 11-point measures (“0 = extremely low” to “10 = extremely high) of mental (M = 4.89, SD = 2.67), emotional (M = 2.45, SD = 2.55), physical (M = 5.37, SD = 3.12), and social (M = 2.06, SD = 2.79).

Validation items for concurrent validity. To assess how perceived demands correlated with entertainment outcomes, we used Oliver et al.’s (2016) two-factor scale assessing enjoyment (three items: M = 6.13, SD = 0.85, ω = .911) and appreciation (three items: M = 3.36, SD = 1.32, ω = .726). The scale assesses entertainment outcomes using seven-point Likert-scaled items (“1 = strongly disagree” to “7 = strongly agree”). In addition, we also assessed player ratings (on a 100-point scale) for ratings of story (M = 36.25, SD = 34.85), gameplay (M = 85.30, SD = 15.85), controls (M = 79.24, SD = 20.17), sound (M = 83.01, SD = 18.09), graphics (M = 77.81, SD = 18.40), and overall game quality (M = 84.81, SD = 12.40).

Another common outcome of gaming is psychological need satisfaction, rooted in a self-determination theory approach to intrinsic motivation (Ryan & Deci, 2000). Need satisfaction was assessed using Ryan et al.’s (2006) Player Need Satisfaction Scale, with three items each for autonomy (M = 4.88, SD = 1.19, ω = .677), competence (M = 5.46, SD = 1.11, ω = .779), and relatedness (M = 2.85, SD = 1.50, ω = .894). All scales used seven-point Likert-scaled items (“1 = strongly disagree” to “7 = strongly agree”).

Presence. Finally, the current study expanded prior work to consider the unique role that presence could play when assessing VR-based video games. To this end, we assessed spatial presence (M = 5.33, SD = 1.20, ω = .863) and social presence (M = 3.27, SD = 1.70, ω = .931; separate five-item scales from Ahn et al. 2016). All scales used seven-point Likert-scaled items (“1 = strongly disagree” to “7 = strongly agree”).

Results

Our analysis is divided into two sections. The first presents the results of a confirmatory factor analysis (CFA) to test the a priori VGDS structure. Following, the latent perceived demand variables are examined for expected correlations with relevant user experience measures. As stated earlier, all analyses here are replications of prior VGDS scale validation research: the original VGDS introduction (Bowman et al., 2018) and translation to German (Koban & Bowman, 2021) and Mandarin Chinese (Bowman et al., 2021b). For convergent, concurrent, and predictive validity testing, we used structural equations models—reported in brief below to highlight notable results (see OSF for data and analysis outputs).
Confirmatory Factor Analysis

CFA was calculated using the lavaan package of R. Using the suggested reporting standards of Bowman and Goodboy (2020) for CFA interpretation, our observed data was a strong fit for the a priori VGDS measurement model: $\chi^2(289) = 458.58, p < .001$, TLI = .928, CFI = .919, RMSEA = .064 (90% CI .053 to .075), SRMR = .064. The a priori five-factor model was a significant improvement on a single-factor model, $\Delta \chi^2 (10) = 1640.80, p < .001$, $\Delta$AIC = 1620, $\Delta$BIC = 1591.

We also examined the latent scores for each of the five VGDS dimensions and found all five to be normally distributed and with strong evidence of internal consistency (using criteria from Hayes & Coutts, 2020). By dimension: cognitive demand ($M = 3.88, SD = 1.27, \omega = .881$); emotional demand ($M = 3.15, SD = 1.41, \omega = .842$); controller demand ($M = 2.74, SD = 1.57, \omega = .937$); exertional demand ($M = 3.84, SD = 1.78, \omega = .910$); social demand ($M = 3.00, SD = 1.63, \omega = .913$). Controller demands were significantly lower than the scale midpoint of 4.00, one-sample $t(143) = -9.64, p < .001$. This makes sense given the progressive embodiment design of most VR-based systems in which natural human inputs are used to control in-game action (Biocca, 1997; Shafer et al., 2014). Overall low scores for social demand make also sense given that most participants ($n = 90$) reported playing alone—Welch’s $t$-test confirmed that solo players ($M = 2.40, SD = 1.34$) felt less social demand than those $n = 45$ playing with others ($M = 3.99, SD = 1.60$; $t(75) = 5.74, p < .001$, Cohen’s $d = 1.11$).

Convergent Validity

When regressing VGDS latent measures on the NASA-TLX score, increased exertional demands were the only VGDS score significantly associated with task load perceptions ($B = .457, p = .011$), replicating prior work. However, we were unable to replicate the relationship between cognitive demands and task load from prior work ($B = -.584, p = .196$). The overall model was not a strong fit, mostly due to having only a single VGDS dimension as a significant contributor: $\chi^2(419) = 728.40, p < .001$, TLI = .865, CFI = .878, RMSEA = .072 (90% CI .063 to .080), SRMR = .092.

Predictive Validity

All predictive validity tests replicated prior work. Cognitive demands increased mental effort ($B = 1.71, p < .001$). Emotional demands increased emotional effort ($B = 1.18, p < .001$). Lower controller demands reduced physical effort ($B = -.340, p = .039$) and exertional demands increased physical effort ($B = .703, p < .001$). The overall model was a strong fit for the data: $\chi^2(373) = 560.42, p < .001$, TLI = .915, CFI = .927, RMSEA = .061 (90% CI .050 to .071), SRMR = .065.

Concurrent Validity

Increased cognitive demands decreased overall game ratings ($B = -2.36, p = .022$), which was unexpected given the overall positive influence of cognitive demands in gaming broadly, and they otherwise did not influence entertainment outcomes. Increased emotional demands predicted appreciation ($B = .900, p < .001$), feelings of relatedness ($B = .487, p < .001$) and story evaluations ($B = 4.16, p < .001$), all replicating prior work on appreciation in video games (Daneels et al., 2021; Oliver et al., 2016). Controls seen as less demanding (or more intuitive) increased game enjoyment ($B = -.290, p < .001$), gaming competence ($B = -.384, p < .001$), and controller ratings ($B = .205, p < .001$), all replicating past work. Controller demands also had an unexpected positive influence on feelings of relatedness (more intuitive controls increasing relatedness; $B = -.168, p = .012$). Exertional demands had a negative impact on story evaluation ($B = -.176, p = .004$). Social demands were aligned with increased feelings of relatedness ($B = .608, p < .001$), as expected from prior work. The overall model was a good fit for the data: $\chi^2(1081) = 4894.64, p < .001$, TLI = .877, CFI = .856, RMSEA = .061 (90% CI .054 to .067), SRMR = .070.

Finally, and given the potential unique importance of presence in VR-based video games, we calculated a second model that examined the influence of each of our five VGDS dimensions on spatial and social presence simultaneously. This analysis revealed spatial presence to be positively associated with emotional demand ($B = .344, p < .001$) and negatively associated with controller demand ($B = -.202, p = .013$). For social presence, we again see a positive influence of emotional demand ($B = .479, p < .001$) and an expected influence of social demands ($B = .648, p < .001$). The overall model was a good fit for the data: $\chi^2(573) = 891.54, p < .001$, TLI = .898, CFI = .907, RMSEA = .063 (90% CI .055 to .071), SRMR = .070.

Discussion

Results suggest that the five-factor structure of the interactivity-as-demand is appropriate for use when studying VR-based video games. Validity testing further indicated that dimensions of that scale are valid and make useful and discrete predictions among focal experiential outcomes—some of which align with extant findings from non-VR games (Bowman et al., 2018, 2021b; Koban & Bowman, 2021), others with unique explanatory value. Here, we focus on the novel findings, as they inform unique considerations for VR-based video games.

Most notably, cognitive demands had a negative impact on overall VR-based video game ratings, which stands in contrast with previous findings on non-VR games where it was found to drive enjoyment (Bowman et al., 2018, 2021b; Koban & Bowman, 2021). While such a result might be in line with other work on increased cognitive load of VR for other types of media (e.g., 360-degree films; Barreda-Ángeles et al., 2021; Pressgrove & Bowman, 2021), it is noteworthy that average cognitive demand scores were lower in the current study as compared to prior VGDS validation research (Cohen’s $d_s = .157–.368$; see OSF for details). Given people’s limited resources, it could be argued that VR games’ emphasis on physical movements (Wu & Lin, 2018) may inhibit the rewarding aspects of cognitive challenges such that effort costs become more salient (Inzlicht et al., 2018). In other words, cognitive demands in video games may be fun and rewarding so long as players do not already have to struggle with increased physical exertion (noted in Liebold et al. 2020). Further evidence
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of this speculation can be found in prior data, noting that physical demands in VR-based video games for the current study are higher when compared to non-VR games from prior work (ds = .292–.1.349; see OSF for details). More generally, this explanation suggests an important tradeoff among demand categories that could be technology-specific—at least for VR games, physical demands might have primacy over other demands. Such tradeoffs were speculated in Bowman (2020) and are central to understanding the interplay of perceived demands and entertainment outcomes in future research and game design.

Concerning users’ experience of spatial and social presence in VR-based video games, our findings largely align with extant literature, thus providing strong evidence for the validity of the proposed demand constructs. Although social presence was overall lower in the current study, emotional and social demands were positively associated with social presence in VR games, Controller demand’s negative association with spatial presence is in line with previous findings showing that non-intuitive controls can compromise players’ game experience (e.g., Rogers et al., 2015; Liebold et al., 2020). However, the positive association between emotional demands and spatial presence is less obvious, although Wirth et al. (2012) demonstrated that emotional involvement can intensify both the perceived salience of a virtual environment and users’ engagement with it. Given that VR players have an expectation of physicality when they enter the experience (Wu & Lin, 2018), there could be “sweet spot” between engaging and over-exercising the physical body key to feeling narratively engaged in VR-based gaming narratives (feeling “in the story,” Pressgrove & Bowman, 2021). However, a quick browse of the games played in this study suggests that narratives were less focal (with exception Half Life: Alyx), so such dynamics would need to be more closely examined in future research. The positive association between controller demand and relatedness could also be explained here, as players who felt more embodied on-screen (Biocca, 1997) might have felt it easier to relate to on-screen others (see also Ahn et al., 2016) and thus, closer to those narratives.

References


Rogers, R., Bowman, N.D., & Oliver, M. B. (2015). It’s not the model that doesn’t fit, it’s the controller! The role of cognitive skills in understanding the links between natural mapping, performance, and enjoyment of console video games. Computers in Human Behavior, 49, 588–596. https://doi.org/10.1016/j.chb.03.027


