Universiteit Leiden

Psychologie
Faculteit der Sociale Wetenschappen

Time perception in virtual reality

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(February, 2017)
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Abstract

In literature, it is suggested that virtual reality (VR) can accelerate time perception. This effect is made use of in several clinical situations, like chemotherapy, but we do not yet know if VR really alters our time perception, or whether it is influenced by arousal or affective valence of the VR stimuli. In this study, time perception in VR is compared to an identical physical environment, with film fragments being shown to the participants. After every fragment, the participants gave an estimation on the perceived length, and gave ratings on the level of arousal and affective valence.

Results show that VR in itself is not the reason for accelerated time perception, rather that it is influenced by arousal and affective valence. For low arousing stimuli the duration of negative film fragments is judged shorter than the duration of positive film fragments, regardless of type of environment (VR or physical). For high arousing stimuli the duration of negative film fragments is judged longer than the duration of positive film fragments, regardless of type of environment.

Furthermore this study explored a specific VR environment, like a manipulated sunrise together with an interaction feature, which showed a trend-level of accelerated time perception for the participants.

It can be concluded that VR can influence arousal and affective valence levels, which in their turn can influence time perception. Further research needs to find out if this concept is useful in clinical situations, like treatments.

Content

1 Introduction

The founder of the oculus, Palmer Luckey believes that virtual reality (VR) may affect the ability of how we experience time. He stated:

> "I think a lot of times we rely on our environments to gain perceptual cues around how much time is passing. It's not just a purely internal thing. So when you're in a different virtual world that lacks those cues, it can be pretty tough. In VR, obviously, if you don't have all those cues — because you have the cues of the virtual world [instead] — then you're not going to be able to make those estimates nearly as accurately" (Miller, 2016).

Palmer Luckey is not the only one who believes that VR affects time perception, for example, VR is already used in several clinical situations, such as during chemotherapy and burn wound treatment. Schneider, Kisby and Flint (2011) concluded that VR is a non-invasive intervention that can make chemotherapy treatments more tolerable, because it alters time perception, which may also work as a distraction during chemotherapy.

Several studies (Hoffman et al., 2008; Sharar, et al. 2007; Das, Grimmer, Sparnon, McRae & Thomas, 2005) show that VR can work as an effective diversion method during treatment of burns resulting in a clinically meaningful degree of pain relief due to patients getting lost in time.

1.1 Time perception

In the previously mentioned studies VR is suggested to work as a distraction method during therapies, but can it really alter our time perception? According to Angrilli, Cherubini, Pavese and Manfredini (1997) three variables are relevant to study this concept; attention and amount of information processing, arousal, and affective valence. Given the empirical evidence so far, it could also be that altered time perception is influenced by arousal and affective valence. These variables are often linked to VR, so it is expected that these variables will influence time perception, than the VR device itself

Subsequently, the variables attention and amount of information processing, arousal, and affective valence can be linked to the internal-clock model (also known as the pacemaker model). The internal-clock model is regulated by a dopaminergic pacemaker that produces neural ticks or pulses that are transferred to the accumulator, which can be seen as a neural counting system that corresponds to a specific time interval. In the working memory system, the contents of the specific time intervals are compared with a reference framework (McGrew, 2006).

One of the variables linked to time perception is attention. If people pay attention, or need to process a lot of information, then it feels like time is flying by, which is in contrast to being in a waiting room, with time seemingly dragging on (Wearden, 2005). This could be explained as a consequence of an interesting stimulus compared with a neutral stimulus, which leads to an underestimation of the interesting stimulus due to a difference in how the stimulus is attended to (Angrilli et al., 1997).

The variable arousal is derived from a subcortical structure that can induce widespread and unspecified activation, called the "neurophysiology's ARAS" (ascending reticular activating system). In particular, the term arousal in psychophysiology refers to the phasic component of the central and sympathetic nervous system activation induced by a brief stimulation, such as a tone or a slide (Angrilli et al. 1997). This activation is of great importance in the perception of time, with an increased arousal lengthening the experience of time, meaning the durations seem to be longer than normal (Burle & Casini, 2011; Droit-Volet & Meck, 2007).

Also, affective valence can influence time perception. Affective valence is known as the intrinsic attractiveness or averseness that we have concerning a situation. It is proven that negative stimuli are judged to be longer than positive stimuli, in similar arousal level (Noulhiane et al., 2007; Droit-Volet & Meck, 2007).

Angrilli et al. (1997) combined the information mentioned above in their study, finding an interaction effect between arousal and affective valence. Angrilli et al. (1997) concluded that for low arousal stimuli, the duration of negative slides were judged relatively shorter than the duration of positive slides. For high arousal stimuli, the duration of negative slides were judged longer than the duration of positive slides. This interaction effect of valence as a function of arousal can be explained by two different mechanisms that are triggered by arousal level; namely controlled attention, and an automatic mechanism related to motivational survival systems (Droit-Volet & Meck, 2007). The latter mechanism is linked to high arousal levels, especially negative situations that require rapid reactions, thinking about “Fight or Flight” reactions. Those reactions work on this mechanism. A rapid reaction is linked to a blood pressure increase, pupil dilation, and muscle contraction, findings that are associated with speeding up the clock.

The above literature shows that time perception is influenced by arousal and affective valence. This brings us back to VR, which is considered as an interactive and sensation arousing instrument (Lehtonen, Page & Thorsteinsson, 2005). VR can elicit some intended emotions (joy, sadness, boredom, anger and anxiety) by changing the environment (Felnhofer et al., 2014). This could mean that it is not the instrument of VR itself that leads to an altered time perception, but rather that the VR device can lead to different emotions and arousing levels, which in turn lead to an altered time perception.

In addition to the arousing and emotional characteristics, immersion is also a very important characteristic of VR. It has been shown that people who play videogames often report the sense of immersion in the game with a particular feature, like music. This immersion creates a feeling of being loss of the sense of time passing (Sanders & Cairns, 2010).

1.2 The aim of the study

The intention of this study was to investigate the perception of time in the physical world (physical cinema) compared to the virtual world (“Oculus Cinema”). It was hypothesised that duration estimation was the same in both environments when controlled for arousal and affective valence. The expectation for low arousing stimuli was that the duration of negative film fragments were judged shorter than the duration of positive film fragments. The opposite pattern was expected for high arousing stimuli.

As an addition to this study, another variable was added to explore the influence on time perception. “Happy Place”, a virtual reality application with specific features was added. An article on Oculus (2016) suggests that “Happy Place” is a virtual space for tranquillity and relaxation, designed to distract from worldly problems like pain, and give rise to positive emotions like ease and calmness. These findings are in line with the treatments mentioned in the introduction, where patients get distracted from pain. Besides that “Happy Place” was added because it makes use of a manipulated sunrise and it is having interactive components, which can influence time perception. Due to the interactivity of “Happy Place”, the expectation was that time passes more quickly in comparison to the “Oculus Cinema”.

Those expectations were set up in an experimental study. This way the influence of VR on time perception and the influence of arousal and affective valence could be tested.

2 Methods and materials

2.1 Design

The study is a mixed within subjects design. The within subjects factors are environment/display (physical cinema setting vs “Oculus Cinema”) compared with arousal (low vs high) and affective valence (negative vs positive), along with the duration estimation of the “Oculus Cinema” compared with the duration estimation of “Happy Place”.

2.2 Participants

The film fragments were tested in a short pilot of 9 participants, men and women without any exclusion or inclusion restrictions. The average age was 33 years old.
After the pilot a total of 29 healthy participants (15 men and 14 women) were recruited through; SONA, a website used by the University of Leiden to collect participants, posters spread around at the University of Leiden, and family/friends of the researcher.
The inclusion criteria were: 18-35 years old, able to converse in English, no history of psychiatric diagnosis, no history of brain injury, no motion sickness, corrected or corrected-to-normal vision, no impaired auditory, no (familiar) history with epileptic disorders.

The participants had an average age of 24.8 (*SD* = 3.13), 19 of them had no previous experience with VR, and 10 participants did have experience. To make sure participants had an “average” time perception, participants needed to say how long the introduction before the experiment lasted, which was compared with the actual instruction time. Nobody over, nor underestimated this for more than twice, which meant that nobody was excluded from the experiment.
Four groups were made to counterbalance the experiment, see table 1.

Table 1. *Distribution participants*

Environment order	Participants	Men/women	Age (*SD*)
Physical cinema, movie 1 – Oculus cinema, movie 2	8	3/5	22.9(*3.09*)
Physical cinema, movie 2 – Oculus cinema, movie 1	7	5/2	24.7(*2.43*)
Oculus cinema, movie 1 – Physical cinema, movie 2	8	4/4	25.8(*2.66*)
Oculus cinema, movie 2 – Physical cinema, movie 1	6	3/3	26.3(3.78)

2.3 Procedure

The whole experiment took approximately 50 minutes per participant. During the experiment all three tasks were counterbalanced to avoid order effects.

First the participant was asked to fill in a basic questionnaire regarding gender, age, and previous experience with VR. During the experiment participants were not allowed to use watches or phones.

Task 1 – Cinema, physical environment: The participant watched eighteen minutes of unique movie fragments. During those eighteen minutes, ten unique time intervals were measured (randomized). After every fragment participants saw a black screen for one minute, during which questions were asked in this period of time regarding arousal and affect valence levels and how long he or she felt they watched the fragment.

Task 2 – “Oculus Cinema”: The second task was exactly the same as in task one, only the participant used the Oculus Rift to watch different movie fragments for eighteen minutes, with ten unique time intervals.

Task 3 – “Happy Place”: The participant was asked to put on the Oculus Rift. They saw a nature environment where they could look around, which lasted 95 seconds. In this way it was comparable with the other (longer) fragments used in the previous mentioned tasks.

2.4 Instruments

2.4.1 Virtual reality

For this study it was important that the participants had the feeling of being present in the virtual environment as studies have shown that one brain area is linked to this kind of feeling. This brain area is the dorso-lateral prefrontal cortex (dlPFC), an area also associated with the control of impulsive behaviour (Beeli, Casutt, Baumgartner & Jäncke, 2008). Jäncke, Cheetham and Baumgartner (2009) found that the dorso-lateral prefrontal cortex is active during virtual reality.

Two virtual environments were used in this experiment; the "Oculus Cinema", and "Happy Place", shown through the virtual reality system, the Oculus Rift.

"Happy Place" was used in this study to explore a totally different setting than the cinema setting. In this application special VR features are added, like a manipulated sunrise, along with being more interactive than a cinema setting.

2.4.2 Cinema and movies

The Cinemec cinema in Utrecht was used to compare the physical environment with the "Oculus Cinema". All the tasks were completed in the movie theatre. The movie theatre looked like the "Oculus Cinema", both the lights and colours almost equal, with the movie shown in 2D through the VR display and the physical cinema.

The movie fragments that were edit are based on the IAPS slides (Lang, Bradley and Cuthbert, 2005). Examples of the movie fragments are: spider, naked couple, kissing people, starving lion, thousands of whale bones, skinny polar bear, baby, birth of cow, baby kitten, new life of penguins and birds, mechanisms, coconut shells, different kinds of fights between people, people falling, and a drunk person. All these fragments are based on different arousal and affective valence levels.

Along with the IAPS slides, the movie could have been seen as sensitive to some participants, which was disclosed in the informed consent and participants could have stopped the experiment in case of negative feelings or discomfort with the fragments.

After every fragment the participant answered a few questions. First: "How long did you think the fragment was in seconds?", and based on the Self-Assessment Manikin scale (SAM) and on the study done by Angrilli et al. (1997) the following questions were also asked on a nine-point scale:

- Arousing: (1) Calm - (5) Medium - (9) Aroused
- Affective valence: (1) Very negative - (5) neutral - (9) Very positive

Since there was not enough time between every time interval, only one minute, the questions with the highest factor loading on the SAM were the most useful for this study (Bradley and Lang, 1994).

2.5 Statistical analyses

All collected data is quantitative with all the tasks being counterbalanced to avoid order effects. The time measurements are in seconds, although for this study the different rates are used instead of raw data. The formula that is used to calculate those different rates: (1- estimated time/actual time)*(-1).

Firstly, the mean score of duration estimation is calculated for all the VR fragments and the physical fragments, to allow for a comparison between the environments. Afterwards a paired t-test was carried out to compare duration estimation in the virtual world in comparison to the physical world.

To find out if there was an influence of arousal and affective valence on duration estimation, a regression analysis was carried out. The dependent factor is duration estimation, with the predictors of arousing and affective valence. Outliers (three or more standard deviations from the mean) were excluded of those analyses.

To examine the influence of special features of VR, “Happy Place” is compared with the “Oculus Cinema”. Again, a paired t-test was carried out to compare the duration estimation in both virtual environments.

3 Results

3.1 Influence of the environment on duration estimation

To conclude if temporal duration is estimated the same in the virtual world ("Oculus Cinema") in comparison to the physical world (physical cinema), a paired t-test was conducted. No significant difference was found in the comparison of estimated duration for virtual reality (M = -0.12, SD = 0.34) and the psychical world (M = -0.13, SD = 0.32), t < 1; d = 0.04. Cohen's effect size value suggested a small effect.

Duration estimation in virtual reality showed an effect at trend-level; participants underestimated time by 0.12 (95% CI, -0.01 to 0.25) compared to a difference score of 0 (in other words a correct estimation), $t(28) = -1.91$, $p = .066$. Duration is estimated significantly lower for the physical world by 0.13 (95% CI, 0.01 to 0.26) compared to a difference score of 0, $t(28) = -2.26$, $p = .032$.

3.2 Influence of arousal and valence on duration estimation

Twenty different regression analyses (for each fragment one) were conducted to see the influence of arousal and affective valence on duration estimation.
For movie one (see table 2), no significant F-values are found, with only a trend-level effect discovered in a fragment about kissing people ($R^2 = .17$, $F(2,26) = 2.684$, $p = .087$; $f^2 = .206$). This fragment is considered as low arousing and the results show that positive valence will increase the duration estimation. Cohen's effect size value suggested a medium to large effect.

For movie two (see table 3), a few significant results show an influence of arousal and affective valence. In a fragment about a kitten, a significant result is found ($R^2 = .22$, $F(2,26) = 3.689$, $p = .039$; $f^2 = .284$). Cohen's effect size value suggested a medium to large effect. This fragment is considered as low arousing/neutral, whereby positive affective valence show an increased duration estimation. Another low arousing/neutral fragment with a significant result is a fragment about newborn animals ($R^2 = .26$, $F(2,26) = 4.666$, $p = .019$; $f^2 = .359$). Cohen's effect size value suggested a large effect. Also for this fragment, positive affective valence increased duration estimation.

For a fragment about mechanisms, a significant influence is found for arousal and affective valence on duration estimation (R^2 = .22, F(2,26) = 3.629, p = .041; f^2 = .279). Cohen's effect size value suggested a medium to large effect. In this case, high arousal together with negative valence increased duration estimation.
A high arousing fragment is about lovers, which resulted positive valence shortening the duration estimation (R^2 = .29, F(2,26) = 5.377, p = .011; f^2 = .414). Cohen's effect size value suggested a large effect.

A trend-level effect is found for a fragment about the drunk person (R^2 = .184, F(2,26) = 2.933, p = .071; f^2 = .225). Cohen's effect size value suggested a medium to large effect.

Table 2. *Influence of arousal and valence on duration estimation, movie 1*

	Movie 1					
Fragment	R^2	F(2,26)	*P-value*	*Effect size* (f^2)*	*Standardized coefficient Beta*	
1. Production of glass	.068	.947	.401	.073	Arousal	-.157
					Valence	.265
2. Spider	.011	.144	.867	.011	Arousal	.105
					Valence	.010
3. Dial indicator	.057	.786	.466	.060	Arousal	.191
					Valence	-.2.19
4. Baby	.076	1.076	.356	.082	Arousal	-.397
					Valence	.441
5. Kissing people	.035	.467	.632	.036	Arousal	.100
					Valence	-.202
6. Starving lion	.142	2.160	.136	.166	Arousal	.374
					Valence	-.090
7. Fighting people	.043	.585	.564	.045	Arousal	.210
					Valence	.035
8. Kissing people	.171	2.684	.087	.206	Arousal	-.491
					Valence	.395
9. Birth of a cow	.080	1.124	.340	.087	Arousal	.213
					Valence	.127
10. Fight	.075	1.059	.361	.081	Arousal	.104
					Valence	.269

*Cohen f^2 values: 0.02 (small), 0.15 (medium), and 0.35 (large)

Table 3. *Influence of arousal and valence on duration estimation, movie 2*

Movie 2						
Fragment	R^2	*F*(2,26)	*P-value*	*Effect size* (f^2)*	*Standardized coefficient Beta*	
1. Kitten	.221	3.689	**.039**	.284	Arousal	-.075
					Valence	.512
2. Whale bones	.072	1.003	.380	.078	Arousal	.262
					Valence	.043
3. People falling	.093	1.332	.281	.103	Arousal	.284
					Valence	.196
4. Briquettes	.034	.453	.640	.035	Arousal	.116
					Valence	-.186
5. Drunk person	.184	2.933	.071	.225	Arousal	.348
					Valence	.240
6. Lovers	.293	5.377	**.011**	.414	Arousal	.514
					Valence	-.561
7. Skinny polar bear	.138	2.076	.146	.160	Arousal	.157
					Valence	.268
8. Newborn animal	.264	4.666	**.019**	.359	Arousal	.186
					Valence	.126
9. Mechanism	.218	3.629	**.041**	.279	Arousal	.532
					Valence	-.144
10. Kissing people	.073	1.3020	.375	.079	Arousal	.038
					Valence	.245

*Cohen f^2 values: 0.02 (small), 0.15 (medium), and 0.35 (large)

3.3 Influence of special features of VR on duration estimation

To explore if there was an influence of “Happy Place” on duration estimation in an accelerated manner, a paired t-test was executed. A trend-level effect is seen in the comparison of “Happy Place” (*M* = 0.04, *SD* = 0.47) and the “Oculus Cinema” (*M* = -0.12, *SD* = 0.34), *t* (28)= -1.83, *p* = .078; *d* = 0.20. Cohen’s effect size value suggested a small effect.

Duration is estimated a bit higher for “Happy Place” by 0.04 (95% CI, -.22 to 0.14) compared to a difference score of 0, *t*(28) = 0.43, *p* = .668.

4 Discussion and conclusion

The aim of the study was to objectively investigate the influence of VR on time perception. It was hypothesised that the duration estimation would be the same in a VR environment compared to a physical environment, and that time perception is influenced by arousal and affective valence. To explore the influence of another VR environment "Happy Place" was added, with the expectation that the duration estimation would have been shorter than the "Oculus Cinema".

As expected the environment did not have a significant influence on the duration estimation. Participants showed no difference in duration estimation for both environments, which is in contrast with the anecdote of Palmer Luckey (Miller, 2016) and the study of Schneider et al. (2011), who expected an influence of virtual reality on duration estimation. These findings can be explained by the findings related to the second hypothesis, other aspects have impact on time perception. Instead of the environment, it was hypothesised that there was an influence of arousal and affective valence on duration estimation, 4 out of 20 fragments showed a significant effect. Interaction effects were found for arousal and affective valence, for example in low arousing fragments, positive valence will increase duration estimation. For high arousing fragments, negative valence will increase duration estimation.
This is in line with the previous study of Angrilli et al. (1997), low arousing stimuli, negative slides are estimated shorter, and high arousing stimuli, positive slides are estimated shorter.

Also in line with the expectation, the result of "Happy Place" compared to "Oculus Cinema", a trend-level was found. Estimation duration was slightly shorter in "Happy Place". A few theories support this result, as mentioned by Lehtonen et al. (2005) VR is interactive and sensations arousing, the "Happy Place" application is more interactive compared to a movie fragment. In this application participants could really look around in the environment and sometimes load specific features by looking at it, for example by looking at the fireplace it started roasting marshmallows.
As mentioned by Sanders and Cairns (2010) immersion may result in loss of the sense of time. During the experiment participants gave feedback about "Happy Place" and people felt like being in the environment, in other words, they felt immersed. The

same result is found in a recent study done by Schatzschneider, Bruder and Steinicke (2016). They used a virtual environment with special VR features, in this case a manipulated sun, which seemed to pass time by more quickly. Their explanation for this result is being focused and feeling immersed. In further studies it is advised to objectify the feeling of presence, by the use of the "MEC Spacial Presence Questionnaire" made by Vorderer et al. (2004).

Results show arousal and affective valence can partly declare the variance. It can be assumed that a number of other variables also contribute to time perception. It is proven that VR can work as a distraction method during therapies. It is interesting to investigate deeper the influence of arousal and affective valence in correlation to the variable distraction.

In follow-up studies it is also recommended to explore the effects of other VR applications, for example, applications which are more interactive and that increase the feeling of immersion. In this way the influence of attention and amount of information processing can be explored.

Finally, it is advised to use a more diverse sample size. It is known that older people estimate time in a different way as their internal-clock is slowing down and time seems to go faster (Marcoen, Rammen & Van Ranst, 2006). For short time frames, used in this study, this will not show a significant difference, but for longer time frames, this can be easier to identify. In this study the fragments varied from 7 seconds to 110 seconds, however, it would be advisable to use longer time frames for the fragments, for example a few minutes, or the length of a whole treatment, like in chemotherapy.

It can be concluded that VR itself does not accelerate time perception in comparison to the physical world, but VR has specific features; it can manipulate our level of immersion, arousal and affective valence. All those aspects affect time perception, which researchers and virtual reality developers can make use of. In the future, virtual reality can have a bigger influence in therapies, but more research is necessary to optimize the influence of immersion, arousal and affective valence in virtual reality and to make therapies possibly more tolerable.

5 Acknowledgements

This study is supported by the University of Leiden, Faculty of Social and Behavioural Sciences. I would like to thank my supervisor, Dr. C.J.M. van der Ham, for giving me the opportunity to write this thesis and have my own input on the content of this project. I also would like to acknowledge A. Cuperus of Triple for his contribution on the content and his bright ideas. Special thanks to Cinemec Utrecht, for the opportunity to use their movie theatre, which really helped the comparison in this study. I also would like to thank Samsung, as they provided the Samsung GearVR. Finally I would like to mention and thank all the participants. I appreciate their cooperation and support.

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