Effects of Valence and Arousal on Working Memory Performance in Virtual Reality Gaming

Gabana, D., Tokarchuk, L., Hannon, E., and Gunes, H.

Presented by **Anish Pimpley**
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Summary

Goal	Detect the effect of **valence** and **arousal** on Working Memory (WM) performance in VR games
Procedure	● Custom VR game played on various difficulty levels in desktop & VR mediums. ● Players self reported valence,arousal and experience for each instance of a game setting ● Heart Rate, and derived features AVNN, rMSSD, LFHF were collected during the game ● Authors establish relationship between valence & arousal with WM given a game instance
Results	● VR as a medium intensifies self reported valence and arousal ● Greater values for affective states in VR correspond to positive improvement in cognitive performance and WM. ● Significant improvement in WM performance in players with lower base WM and in lower difficulty levels. ● Results linked to flow theory [link] , where full immersion and engagement are triggered by allowing users to overcome challenges, thus generating positive affect.
Relevance	In closed loop feedback based games for training cognitive control, use of valence and arousal as target metrics improve outcomes for cognitive performance and working memory. This effect is amplified by using VR as the game medium.

Terms and Disambiguations on last page.

Related Work

Studies linking cognition and emotions

- WM. Bennion et al. and Yeh et al. hypothesize that both positive / negative valence enhance WM. However, arousal only helps WM to a certain point.
- Physiological approaches observed that low Heart Rate variability is observed in players with lower WM

Instances of using affect detection in gaming

- Riva et al. suggest VR as an affective medium and observe that the level of presence is directly proportional to intensity of experienced emotions.
- Mishra et al. use affective states to provide feedback in adaptive closed feedback video games.
- Affect detection in games has been used for therapeutic VR games to help autistic children socialize and engage with society.

Affect in cognitive training video games

- Neuroracer has been used to boost cognitive skills in the elderly by using appropriate challenge for cognitive skills.
- Project :EVO has been used to treat depression and emotional disorders inspired from Neuroracer.
- Both engage the subject by designing heuristics for rewards and storylines
- Mishra et al. suggest the use of physiological and motion information in addition to performance metrics as input channels to closed loop feedback systems in such games. However they do not elaborate on a concrete set of suitable inputs.

The Study

The game :

- Endless running game - Memory Break, inspired from Smash Hit.
- Throw balls at stationary objects and avoid obstacles
- Every 30s a random sequence has to be remembered acc. To Op. Span

3 levels levels of difficulty - easy, medium, hard (more obstacles and faster)

Devices:

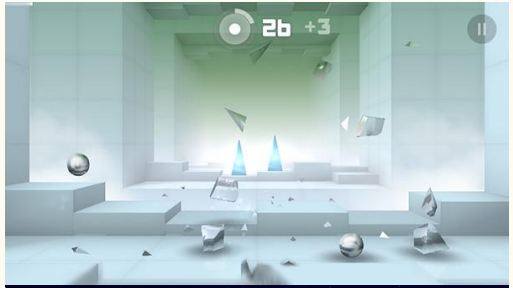
- VR : Leap motion
- HR tracking : Polar H7 heart tracking sensor

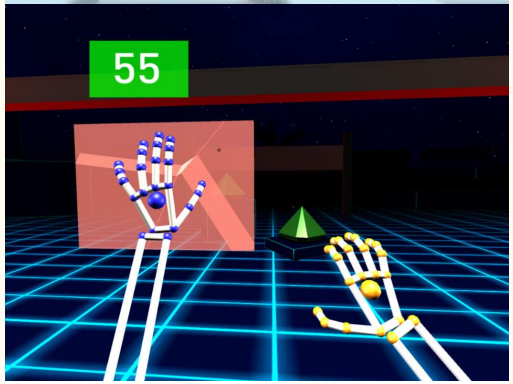
Participants:

- 15 M ,15 M , w. Mean age 26.43
- All variables and participant readings were normalized wrt. their cohort
- Participants divided into 17 high -13 low types, acc. to base WM.
- Patients report arousal, valence and experience acc to following bar graph.

Tests

- ANOVA between game medium and difficulty settings.
- Statistical significance reported for every reading
- Spearman's coefficient to estimate relationship of self reported variables
- WM performance reported using a LME model
- Likelihood ratio tests are used to evaluate the goodness of fit
- WM computed using the OSpan test





Key Results

- VR elicited significantly higher HR, arousal, enjoyment, valence and immersion than Desktop at the difficulty level (2) that saw best WM performance. (fig. 2)
- Self reported valence and arousal correlated significantly with immersion in both mediums.
- Participants with low base WM saw significant WM increase in the VR medium over desktop. (fig. 3)
- Arousal increased with Difficulty for all participants. But, Valence peaked or stagnated for both mediums at the 2nd difficulty level (fig. 4)
- Results of LME model in show Valence and Arousal are significant predictors of WM. (table. 1)
- **Conclusion** :
  The best WM score is obtained when participants felt challenged (high arousal) yet successful (high valence)
- The improved immersion from affective states when using VR, can improve WM performance

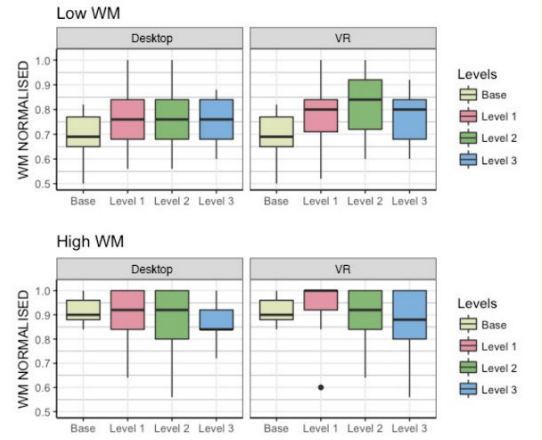


Figure 3. WM performance of subjects with low and high WM capacity

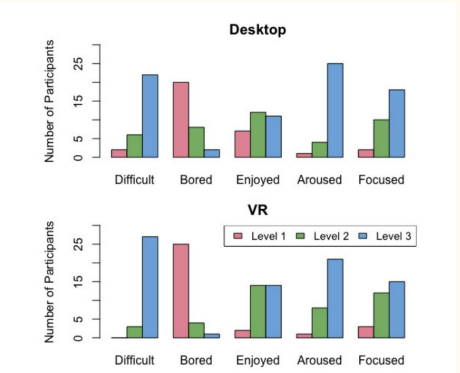


Figure 2. Self-reported comparison levels in each interaction mode

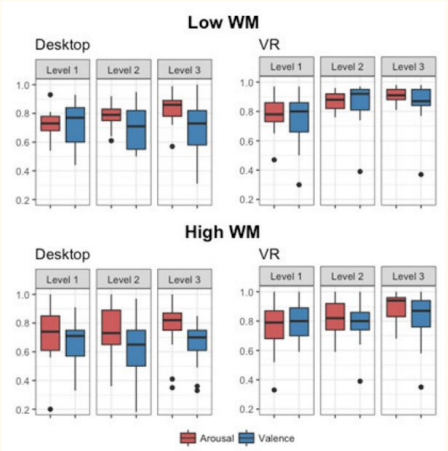


Figure 4. Self-reported arousal and valence of players with low and high WM. Note: Arousal and valence are two separate dimensions of affective

TABLE 1. LME MODEL OF WM

	Estimate	Std. Error	df	t	p
(Intercept)	19.54	1.17	175	16.71	<.001
Valence	6.13	1.12	161	5.47	<.001
Arosual	-3.79	1.52	170	-2.49	<.01

TABLE 2. LME MODEL OF IMMERSION

	Estimate	Std. Error	df	t	p
(Intercept)	1.98	.43	170	4.55	<.001
WM	.03	.02	179	1.55	.12
IM (VR)	.62	.09	151	6.66	<.001
HRV rMSSD	-3.79	.19	179	1.88	.06

Benefits / Merits

- Improving WM performance is a vital part of therapeutic games for helping those with disorders like autism.
- Authors show strong proof that affective states are strong predictors of WM and benefits of using VR as a medium for the same.
- This provides strong motivation for closed loop feedback games to include affective states in their difficulty optimization process.
- The results are supported with strong statistical metrics establishing statistical significance of the results.
- The results were compared against valid baselines, and normalized against the base states of every individual participant. The control variables were well established for each experimental instance.
- Participants were part of a balanced age, gender and user type demographic. They were also not seasoned gamers.
- The mediums were practically same as industry products and the game was directly adapted from a popular iOS game. Thus, the results would translate well to real world products.
- Results consistent with previously hypothesized relationships proposed in related work.

Shortcomings / Limitations

- Does not account for changes HRV due to VR being a more active medium
- The WM model using LME, is low capacity. Authors will be using ML & SVMs in future works
- 30 participants may be too few to conclusively state finding. (though results are statistically significant)
- The authors do not establish causal relationships. Only correlations are stated.

Takeaway

- The paper highlights that with time, affective states in interactive mediums will gain increasing importance, because their effectiveness is dependent on the immersion and believability of the medium itself.
- With VR games collecting user metrics from multiple channels, affective states can integrated more effectively with game AI systems.
- Knowing the merit of including affective states in such games, opens up possibilities for using more sophisticated emotion models than the dimensional theory.
- Can directed graphical models be used to model relationship between variables ? Directed nature can be used to establish causation.
- Can affective metrics be used in real time to continuous change difficulty in games, instead of over discrete game instances ?
- An experiment with a larger cohort (open sourcing the game), despite compromising on controlled trials would be interesting to see. More data will allow for training sophisticated high capacity models as well.

Terms and Disambiguations

- **WM** : Working Memory - short-term memory that is concerned with immediate conscious perceptual and linguistic processing
- **AVNN** : average of normal-to-normal intervals in Heart Rate
- **rMSSD** : root mean square of successive differences in Heart Rate
- **LFHF** : low-high frequency ratio in Heart Rate
- **VR**: Virtual Reality
- **ANOVA** : Analysis of Variances
- **LME** : Linear Mixed Effects models (using arousal and valence as the only predictors for WM)

Thank You.