Human Computer Interactions and Task Performance

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ABSTRACT

As humans start to spend more time in collaborative virtual environment (CVE), coordinating the interaction between the humans in these environments is becoming increasingly important. We have been investigating one aspect of such coordination, namely the issue of an avatar's "personal space". Intuitively it can be expected that CVE users might decrease their task performance when their avatar personal space is invaded since this socially unacceptable act tends to cause anxiety. To investigate the effect of personal space invasion on a user's task performance, we have conducted a controlled experiment measuring the effect of personal space invasion on a user's task performance. The results of the experiment suggest that a user whose personal space is invaded performs more slowly than a user whose avatar's personal space is not invaded

Keywords

Interaction, personal space, invasion, task performance

1. INTRODUCTION

Many researchers have defined personal space (PS) in the physical world as an area with invisible boundaries surrounding individuals which functions as a comfort zone during interpersonal communication [Dos69] [Hal59] [Aie87]. Personal space is often referred to as "interpersonal distance" – the distance apart from each other that conversational partners adopt. Personal space invasion in the physical world occurs when an individual enters another's personal space.

The emergence of new technologies such as internet bandwidth, internet protocols, and powerful graphics desktop computers has enabled collaborative virtual environments (CVEs) to be used with potential applications ranging from entertainment and tele-shopping to engineering and medicine. Indeed, CVEs are being used to support research [Son01], training [Oli00], education [Joh99], and community activities [Lea97]. Thus, people use CVEs for undertaking several tasks that require interaction and navigation such as virtual socializing, virtual learning, and virtual training. These human-to-human interactions through CVE might involve accidental or intentional personal space invasion events of their avatars. Indeed, an observation of the avatar users' behaviour in a CVE has shown that these events did happen, albeit infrequently [Nas04]. As personal space invasions generate anxiety and discomfort in CVEs [Bec98] [Jef98] [Nas04], it is important to investigate their impacts on task performance. This paper therefore reports on an experiment designed to measure the effects of personal space invasion on a user's task performance in a CVE.

The rest of the paper is organized as follows. In section 2 we explain the rationale of the experiment and define the experimental hypotheses. The experimental setup is described in section 3. In section 4 we report on the analysis of the recorded measurements and in section 5 we summarize our findings, discuss their implications, and identify several directions for future research. Finally, in section 6 we offer some concluding remarks.

2. THE RATIONAL OF THE EXPERIMENT AND HYPOTHESES

The goal of our experiment is to quantitatively measure the effects of personal space invasion on a user's task performance in a desktop computer CVE. In order to formulate our hypotheses for the experiment, we reviewed research from both psychology about anxiety and personal space invasion in the physical world.

Anxiety has been known in psychology as a feeling of unease, apprehension or worry. It may be associated with physical symptoms such as rapid heart beat, feeling faint and trembling [Sie77]. However, a small degree of anxiety is an essential force that drives humans to do more work to accomplish their goals. For example, if a worker has not been productive, the fear of criticism from the supervisor may get him/her anxious and this may help him/her to be more productive. On the other hand, elevated anxiety level and stress arousal has been found to affect task performance negatively in many businesses [Aie75]. For example, it has been shown to have a negative impact on organizational commitment, sales personnel's commitment to quality, and eventually perceived service quality [Ben84] [Goo92] [Jac85].

Personal space invasion (PSI) in the physical world tends to produce different signs of discomfort and anxiety, [Hal59] [Alb70] [Aie80] which in turn impairs task performance negatively in many businesses [Aie75]. Similar to the physical world, personal space invasion effect in a CVE has been found to cause anxiety and discomfort (cf. section1) but its influence on task performance in the CVE is not determined yet. Thus, this paper investigates the effect of personal space invasion on task performance in a CVE. In order to investigate this, we conducted a controlled experiment to investigate the following hypotheses:

H1: A CVE's user whose avatar's personal space is invaded requires more time to complete a task than a user whose avatar's personal space is not invaded.

H2: A CVE's user whose avatar's personal space is invaded produces more errors when completing a task than a user whose avatar's personal space is not invaded.

Since anxiety in the physical world has been shown to impair performance in a wide range of cognitive functions including attention, memory, and working out some mental mathematical problem [Sie77] [Spi66], the experiment in this paper measured the effects of personal space invasion in the CVE on a task consisting of three sub-tasks related to attention, memory, and mental arithmetic.

The task completion time and accuracy of the participants whose avatar personal space was invaded was compared against the task completion time and accuracy of the participants whose avatar personal space was not invaded. The differences in performance time and accuracy were then analysed.
The dependent variables of the experiment are the time spent on the task (TOT) and the accuracy of the task results (ATR). The independent variable of the experiment is whether or not the participant's personal space is invaded. The control variables of the experiment are avatar genders since avatar gender has an impact on personal space invasion anxiety level in the CVE [Nas04b].

3. THE EXPERIMENTAL SETUP

In our experiment, 2 groups of different participants were involved (i.e. non-invaded and invaded groups). Each group consisted of 8 participants (4 males and 4 females). The participants of the two groups were treated equally and conducted the same task except that while the participants of the second group were doing the task, their personal space was invaded by a confederate -- a special participant who had been instructed by the experimenter to invade the personal space of participants. None of the participants had prior experience of CVEs. The experiment was conducted in a virtual location consisting of a virtual house constructed in ActiveWorlds (www.activeworlds.com), a CVE that runs on the internet. There were three signs hanging from the ceiling with different colours (i.e. white, yellow, and red), in the virtual house, see Figure 1.

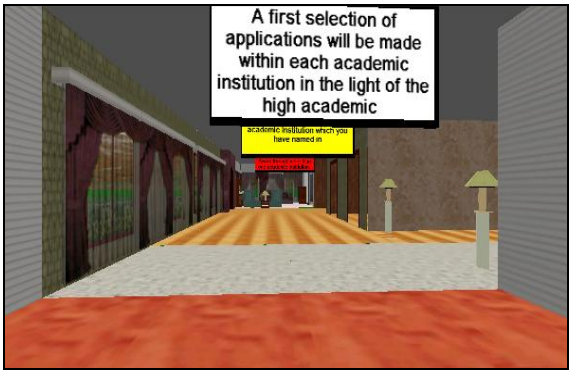

Figure 1: The three signs in the virtual house

We requested the participants to conduct the following experimental tasks in the CVE without writing any kind of notes while doing them:

i- Count the number of words in the white sign.
ii- Add the number of the words in the yellow sign to the number of words counted in the white sign.
iii- Subtract the number of the words in the red sign from the total number counted in the white and yellow signs.

The nature of these tasks was designed because it has been argued in the literature (cf. section 2) that anxiety has been shown to impair performance in a wide range of cognitive functions including attention, memory, and mental arithmetic [Sie77] [Spi66]. Specifically, the task required the participants to pay attention while counting words in each signs, to use their memories to remember the number of the counted words in each sign, and to solve a simple mathematical problem by subtracting the number of words in the white and yellow signs from the number of words in the red sign.

The experiment consisted of 2 sessions. In the first session, there was no personal space invasion: the given tasks were carried out by the participants and results were recorded. In the second session, which happened a few days later, different participants from those who participated in session 1 carried out the same tasks but their personal space was invaded once while they were counting the words in each sign. Each invasion (which involved the confederate avatar getting very close to the participant's avatar) lasted for around 5 seconds and took place from the front. Participants in the second session (i.e. the invaded group session) of the experiment were told, prior to the experiment, that the virtual house is open to the public and anyone can be in it at the time of the experiment. They were instructed to ignore anyone in the house and to complete the task no matter what happened during the experiment as quickly as possible while maintaining accuracy. A stopwatch was used by the experimenter to measure the TOT for each participant of the given task. The stopwatch was started when the experimenter announced the starting time of the experiment and ended exactly when the participants announced the final number of words he or she had calculated.

4. RESULTS AND ANALYSIS

The experimental results of the time taken to complete the tasks and the issue of whether the participant completed the task correctly will be reported and analysed in turn. The software package Statistical Package for Social Scientists (SPSS) was used for the analysis of the data [Sps99] and details of the test used can be found in the SPSS User's Manual online help [Sps99] or [Bla00] [Eve95].

4.1 Time of Task (TOT)

The times taken by the participants to complete the task are shown in Table 1.

User No	Participant personal space	TOT values in minutes
1	Not invaded	1.53
2	Not invaded	1.43
3	Not invaded	1.55
4	Not invaded	1.51
5	Not invaded	1.41
6	Not invaded	1.56
7	Not invaded	1.41
8	Not invaded	1.50
9	Invaded	1.80
10	Invaded	1.91
11	Invaded	1.61
12	Invaded	1.56
13	Invaded	2.14
14	Invaded	1.70
15	Invaded	2.10
16	Invaded	2.09

Table 1: Time spent on the task for each of the participants

Before testing our hypothesis:

H1: A CVE's user whose avatar's personal space is invaded requires more time to complete a task than a user whose avatar's personal space is not invaded.

It is necessary to examine whether the distribution of times on task (TOT) is *normal* to assess whether it is appropriate to use *parametric* tests, such as the *t*-test, which assume normality.

Examining the distribution of the times on task for all participants together (Figure 2.a and Table 2), it can be seen that the distribution varies from the normal distribution. It is positively skewed (*skewness* = 0.89), that is it has a long right-hand tail, it is flattened (*Kurtosis* = -0.63) and significantly deviates from the expected probability distributions expected for the normal distributions (p = 0.016 and 0.012 for the *Kolmogorov-Smirnov* and *Shapiro-Wilk* tests respectively).

It is possible that two discrete parametric distributions, from the invaded and non-invaded participants have been combined to form a distribution that no longer appears parametric. To explore this possibility these distributions are examined separately (Figures 2.b and 2.c, and Table 2.1 and 2.3). This appears to improve the situation, indeed, the positive skew is reduced to smaller negative skews and the *Kolmogorov-Smirnov* and *Shapiro-Wilk* tests show no significant deviation from normal distribution. However, on closer examination the flatness (*Kurtosis* = -1.9 in both cases) of the distributions is more marked. Also the

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actual statistical values of the *Kolmogorov-Smirnov* and *Shapiro-Wilk* tests have not been reduced, the reduction of significance is in effect due to halving the sample size, and not by the component distributions conforming more to normal distributions.

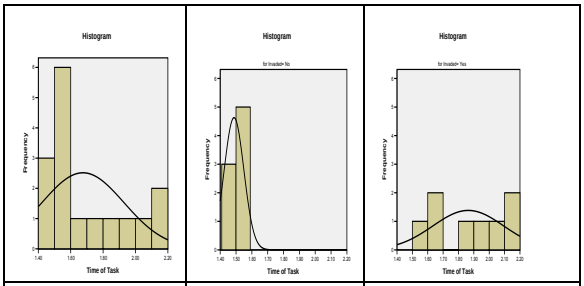

Figure 2.a: All Participants	Figure 2.b: Non-Invaded	Figure 2.c: Invaded

Figure 2: Histograms of times of task with normal distribution curves

Distribution	***All Participants***		
Descriptors	**Stat.**	**Std Error**	
Mean	1.68	0.063	
Skewness	0.89	0.564	
Kurtosis	-0.63	1.091	
Normality Tests	**Stat.**	**df**	**Sign.**
Kolmogorov-Smirnov	.24	16	.016
Shapiro-Wilk	.85	16	.012

Table 2.1: Descriptors and Normality Tests for Times of Task Distributions (All participants)

Distribution	***Non-Invaded***		
Descriptors	**Stat.**	**Std Error**	
Mean	1.49	0.022	
Skewness	-0.32	0.75	
Kurtosis	-1.9	1.5	
Normality Tests	**Stat.**	**df**	**Sign.**
Kolmogorov-Smirnov	.20	8	.200
Shapiro-Wilk	.87	8	.151

Table 2.2: Descriptors and Normality Tests for Times of Task Distributions (Non invaded participants)

Distribution	*Invaded*		
Descriptors	**Stat.**	**Std Error**	
Mean	1.86	0.08	
Skewness	-0.05	0.75	
Kurtosis	-1.9	1.5	
Normality Tests	**Stat.**	**df**	**Sign.**
Kolmogorov-Smirnov	.21	8	.200
Shapiro-Wilk	.90	8	.309

Table 2.3: Descriptors and Normality Tests for Times of Task Distributions (invaded participants)

Given the above considerations, the non-parametric *Mann-Whitney U* test will be used instead of a *t*-test to determine whether there is a significant difference in the time of tasks for the invaded and non-invaded participants. This test makes no assumption about the distribution of the results, but ranks all the results and sums the ranks associated with each group. The results of this ranking process are given in Table 3 below, and the chance of this ranking occurring by chance ($p<0.001$) is very highly significant. Hence the hypothesis is supported: invaded participants take longer to complete the task.

Participant	N	Mean Rank	Sum of Ranks
Non-Invaded	8	4.56	36.50
Invaded	8	12.44	99.50
Total	16		

Table 3: Results Ranking for Mann-Whitney U Test

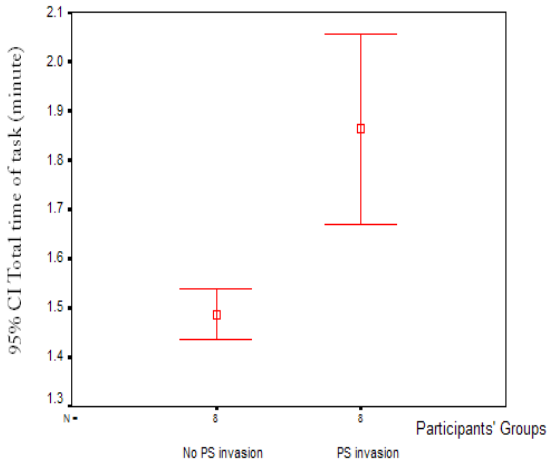

Figure 3: Means and 95% Confidence Interval of the times of task

Figure 3 shows the means and 95% confidence intervals of the times on tasks. This should be treated cautiously, since the calculations of these values assume parametric, that is normal, distributions. However, this graph does illustrate the differences in average time. From Table 4 it can be calculated that on average the participants whose space is invaded spent 0.37 seconds longer on the task than the other participants who spent on average 1.49 seconds. That is the invaded participants spent on average 25% longer on the task, which would seem a substantive increase.

4.2 Participants with Correct Answers

The other result collected from each session, is whether the participant achieved the correct result at the end of the task. These results are summarised in Table 4, split by participants that were non-invaded or invaded.

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Participant	Answer		Total
	Wrong	Right	
Non-Invaded	1	7	8
Invaded	3	5	8
Total	4	12	16

Table 4: Summary of Participants Answers

Since each session and hence each entry in Table 4 is independent, this represents a two by two contingency table. Figure 4.a represents this graphically. Whether the entries in this table are significantly different from those that one would expect by chance can be tested using the *Fisher's exact test*. This test evaluates the sum of the probabilities of all the possible tables with the same marginal totals, but with more extreme distributions. In this case, there is no significance in these results ($p = 0.57$). Therefore the second experimental hypothesis (H2) is not supported:

H2: A CVE's user whose avatar's personal space is invaded produces more errors when completing a task than a user whose avatar's personal space is not invaded.

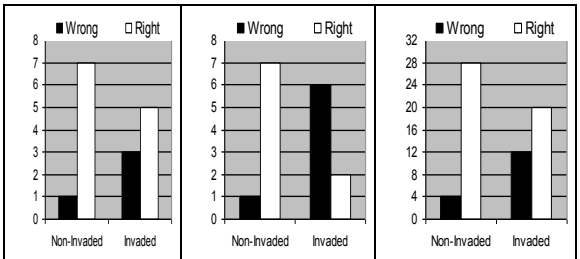

Figure 4.a: Actual Accuracy of Answers	Figure 4.b: Form required for a significant results	Figure 4.c: Larger experiment with same pattern

Figure 4: Bar Charts of Contingency Tables

However, it should be pointed out that the power of this test is relatively poor. For example in order to a significant result with this number of participants, maintaining 1 non-invaded participant making a mistake, 6 invaded participants would have to make an error. The contingency table for this distribution would look like Table 5 and Figure 4.b. Alternatively, if the same distribution as shown in Table 6 were maintained for a larger experiment, the experiment would need to be 4 times as large to produce a significant result (i.e. 64 participants).

Participant	Answer		Total
	Wrong	Right	
Non-Invaded	1	7	8
Invaded	6	2	8
Total	7	9	16

Table 5: Hypothetical table that would show a significant result

The contingency table for these hypothetical results would take the form of Table 6 and Figure 4.c.

Participant	Answer		Total
	Wrong	Right	
Non-Invaded	4	28	32
Invaded	12	20	32
Total	16	48	64

Table 6: Hypothetical table for a larger experiment

In other words the power of this experiment is too low to provide convincing evidence either way about whether the accuracy of the participants is affected by invasion of their personal space. Either a much larger experiment would be required or a more discriminating measure of accuracy, for example scoring each participant over a number of tasks.

5. DISCUSSION

Our experiment gives some preliminary evidence to suggest that the time needed to complete a task by a CVE user will increase significantly if that user's personal space is invaded. Although our data does not confirm that personal space invasion significantly affects accuracy of task completion, it can nevertheless be suggested, based on our results, that CVE users' avatar personal space should be protected during serious works in the virtual environment.

Whilst our experimental results give some evidence to suggest that personal space invasion has an influence on task performance in the CVE, these results should be considered with caution. One reason for caution is that it might be argued that our results might be due to task interruption rather than to personal space invasion as such. The task interruption explanation, however, contradicts a conclusion of Zijlstra et a1. [Zij99], who found that a participant completed a task faster when that task was interrupted. Unlike our experiment, the Zijlstra study was conducted in a non-CVE environment and participants were not instructed to perform the tasks as quickly as possible. Nevertheless, despite these differences, the Zijlstra study does perhaps lend credence to the space invasion rather than task interruption explanation of our results. A further reason for caution when considering our results is that the tasks assigned to the participants were

relatively simple and somewhat artificial. Again, the instruction to the participants of the second (invaded) group to ignore other people may also have had an effect on results. Another reason for caution is that our results may be caused by distraction instead of personal space invasion.

6. CONCLUSION AND FURTHER WORK

In this paper we have outlined an experiment that measured the task performance during interactions that involves personal space invasion and non personal space invasion in the CVE.

The experimental results suggest that personal space invasion anxiety in the CVE increases the time needed to complete a task but provide no evidence that personal space invasion decreases accuracy. The implication of our work suggests that avatar personal space in the CVE should be protected during serious virtual interactions so that these users can perform their tasks more efficiently.

In this study, we focused only on time and accuracy as factors to measure task performance. While this has produced a straightforward result, it might be more accurate to include other factors in measuring task performance such as the characteristics of the participants and the complexity of the assigned tasks. Therefore, future work to investigate these issues is recommended.

7. REFERENCES

[Aie75] Aiello, J. R., Epstein, Y. M., & Karlin, R. A. Effects of crowding on electrodermal activity. Sociological Symposium, 14, 43-57, 1975

[Aie80] Aiello, J., Thompson, D. Personal Space, Crowding and Spatial Behaviour in a Cultural Context in Altman, Rapoport and Wohlwill, 107-178, 1980

[Aie87] Aiello, J. Human Spatial Behaviour Handbook of Environmental Psychology Wiley Inter-science. New York, 1987

[Alb70] Albert, S, Dabbs, J. Physical distance and persuasion. Journal of Personality and Social Psychology, 15; 265-270, 1970

[Bec98] Becker, B., Mark, G. Social Conventions in Collaborative Virtual Environments. In: CVE 98. Manchester. 1998

[Ben84] Behrman, N., Perreault, D. A role stress model of the performance and satisfaction of industrial salespersons. Journal of Marketing 48: 9-21, 1984

[Bla00] Bland, M. An Introduction to Medical Statistics, 3rd edition, Oxford University Press, Oxford. 2000

[Dos69] Dosey, M., Meisels, M. Personal space and self-protection Journal of Personality and Social Psychology, Issue 11, pp 93-97, 1969.

[Eve95] Everitt, B. S. The Cambridge Dictionary of Statistics in the Medical Sciences, Cambridge University Press, Cambridge. 1995.

[Goo92] Goolsby, R. A theory of role stress in boundary spanning positions of marketing organizations. Journal of the Academy of Marketing Science 20:155-164, 1992.

[Hal59] Hall, E. The Silent Language. Doubleday, N.Y 1959.

[Jac85] Jackson, E., Schuler, S. A meta-analysis and conceptual critique of research on role ambiguity and role conflict in work settings. Organizational Behaviour and Human Performance 36:16-78, 1985.

[Jef98] Jeffrey, P. Personal Space in a Virtual Community. In: Human Factors in Computing Systems (CHI '98 Summary), Los Angeles. 1998.

[Joh99] Johnson, A. The Round Earth Project: Collaborative VR for Conceptual Learning, In IEEE Computer Graphics and Applications, 60-69, 1999.

[Lea97] Lea, R. Collaboration in 3D Spaces on the Internet", Journal of Collaborative Computing, No. 6, 227-250, 1997

[Nas04a] Nassiri N., Powell, N., Moore, D. Collaborative Virtual Environment Layouts and Personal Space Invasion Anxiety Level. proceedings of IIT2004, Dubai, UAE, 2004.

[Nas04b] Nassiri, N., Powell, N., Moore, D. Avatar Gender and Personal Space Invasion Anxiety Level in Desktop Collaborative Virtual environment. Virtual Reality Journal, 8, 107-117, Springer Verlag, London. U.K., 2004.

[Oli00] Oliveira, C. A. Collaborative Virtual Environment for Industrial Training, Proceedings of VR 2000, p. 289, 2000.

[Sie77] Sieber, J., O'Neil, H.F., Tobias, S. Anxiety, Learning and Instruction. Hillsdale, NJ: Erlbaum. 1977.

[son01] Sonnenwald, D. Designing to support collaborative scientific research across distance, The nano Manipulator environment. In Collaborative Virtual Environments. London: Springer Verlag, 202-224, 2001.

[Spi66] Spielberger, C., Anxiety and Behavior. New York: Academic Press. 1966.

[Sps99] SPSS Base 10.0 User's Guide, SPSS Inc, Chicago, Ill. 1999

[Zij99] Zijlstra, H., Roe, R, Leonora, A., and Krediet I. Temporal Factors in Mental Work: Effects of Interrupted Activities. Journal of Occupational and Organizational Psychology, 72, 163-185, 1999.