# Analyzing for emotional arousal in HMD-based head movements during a virtual emergency

C. Becker-Asano[1], D. Sun[1], C. N. Scheel[2], B. Tuschen-Caffier[2], and B. Nebel[1]

[1] Institut für Informatik, Georges-Köhler-Allee 52, 79110 Freiburg, Germany
{basano,sun,nebel}@informatik.uni-freiburg.de
[2] Institut für Psychologie, Engelbergerstraße 41, 79106 Freiburg, Germany
{corinna.scheel,brunna.tuschen-caffier}@psychologie.uni-freiburg.de

**Abstract.** This paper reports on results of a statistical analysis of human players' head-movements. Forty-one participants were asked to cope with an unexpected emergency in a virtual parking lot. Before the virtual reality exposure began, half of the participants watched an emotion-inducing movie clip and the other half an emotionally neutral one. The analysis of the acquired questionnaire data reveals, however, that this emotion induction method seems to have been rather ineffective. Thus, it is not surprising that only very weak between group effects are found when analyzing for differences in head movements around the emergency event. In general, horizontal head movement speed is found to be on average significantly faster during the first fifteen seconds directly after the emergency event as compared to just before and another fifteen seconds later. These findings are in line with previous results of an analysis of the acquired physiological data, further substantiating the conclusions drawn.

## 1 Introduction and motivation

Recently, the visual quality of virtual characters in computer games reached such a high level that they are able to convey a wide range of emotions very convincingly by body posture and facial expressions. In addition, the visual effects of such interactive games are now comparable to those of cinematic productions. The Affective Computing community can benefit from this high realism in that new means to acquire data on emotions during interaction are realizable. The recent availability of affordable head-mounted displays with in-built inertial measurement units (IMU) (e.g. Oculus Rift) not only enables novel gaming experiences for the consumer market, but the acquired head movement data might also be useful to recognize emotions during gameplay.

Accordingly, we aim to develop and test means to detect emotional arousal online based on the available head movement data. In contrast to the rather slowly changing physiological attributes, such as heart rate or skin conductance level, a participant's head movement can be expected to respond rather quickly to emotion arousing or stressful events. In addition, even a prevailing background emotion or general increase in arousal could lead to a significant change in head movements. This paper reports on our first attempt to extract and analyze such features from empirical data that were collected during an interdisciplinary collaboration between computer scientists and psychologists.

The remainder of this paper is structured as follows: Section 2 presents and discusses related work, before in Section 3 the research goal and the technological background are explained. Section 4 details the procedures taken in the study and, in Section 5 its results are given. At last, general conclusions are drawn.

## 2 Related work

Virtual Reality (VR) technology has been used, for example, to train surgeons [1], to treat posttraumatic stress disorder (PTSD) in veterans of the Iraq war [2, 3], or as a means to evaluate emotion simulation architectures driving virtual humans [4, 5]. Furthermore, a VR setup has evoked similar responses to violent incidents in human observers as can be expected in real world situations [6] given that a high degree of plausibility could be achieved and maintained. The software used to realize these applications range from game engines such as Epic's Unreal Tournament [2, 3, 5] to a number of custom made installations [7, 4] with proprietary software components. They are combined with different display technologies such as panoramic, auto-stereoscopic, or head-mounted displays (HMDs), or even CAVEs (CAVE Automated Virtual Environment, [8]). The VR-related aspects of a project for PTSD treatment are meant to teach the patient "coping skills" [9] through virtual exposure. For an empirical study on the link between presence and emotions Riva and colleagues [10] used an HMD with head-tracking and a joystick for navigation. They successfully induced an anxious mood in participants only by systematically changing visual and auditory components of a virtual park scenery.

Already more than ten years ago Cowie et al. [11] expected entertainment to be one of the applications for computational emotion recognition. Their overview, however, does not include any work on emotion recognition based on body or head movements. Later, head tilt frequency was used as a parameter to detect head nods in the context of a fatigue detection system [12]. In the human-computer dialog context the importance of head movements is generally acknowledged [13, 14] and a system for automatic detection of the mental states "agreeing, concentrating, disagreeing, interested, thinking and unsure" [15] from video streams consequently includes a number of head orientations. To the best of our knowledge, however, mechanisms to derive emotion-related parameters from head movements during computer games have not been investigated.

## 3 Experiment outline

### 3.1 Research goal

In general, we aim to develop novel technological means to detect emotional arousal of humans while they are interactively exposed to potentially dangerous


Fig. 1: Technical setup with the head-mounted display and the Colibri IMU (left) and the joystick's button allocation (right)

events. The technological hard- and software setup (see Section 3.2) has already been shown to be similarly emotion arousing as watching a short clip of a horror movie [16].

Here we want to explore, if increased stress or fear levels affect a players head movements. Thus, we set out to analyze the acquired head movement data and relate the result to previously analyzed physiological data. Two research questions summarizes our concerns:

1. $RQ_1$: Did our emotion induction method have the desired effect of inducing fear and stress and, if so, to what extent?
2. $RQ_2$: Does a sudden, emotion eliciting event during the VR exposure significantly change a player's head movement speed and do previously induced emotions affect these movements as well?

The first research questions is addressed by performing a between-groups, repeated measures analysis of the questionnaire data. In order to address the second research question within-subject, repeated measures analyses of variance (ANOVAs) of four segments of head movement data around a decisive moment during the experimental session is conducted. The complete study design is described in Section 4, after the hard- and software setup has been explained next.

### 3.2 Technology

**Hardware setup** To achieve an immersive setup we opted for Trivisio's "VRvision HMD" [17], which features two SVGA AMLCD 800x600 color displays with 24 bit color depth, 60 Hz video frame rate, and a field of view of 42° diagonally and 25° vertically; cp. Fig. 1, left. The USB-powered HMD features a pair of Sennheiser HD 205 headphones, which are connected to the same PC. An ATI Sapphire Radeon 5870 together with an Intel Core-i5-760 CPU drives the HMD under Windows 7 (64bit). A USB-powered "Colibri" tracker—mounted on top of the HMD (cp. Fig. 1, left)—provides us with the participant's head movements.

The participants used a Thrustmaster T-16000M joystick to navigate inside the virtual environment; cp. Fig. 1, right. They can move forward and backward

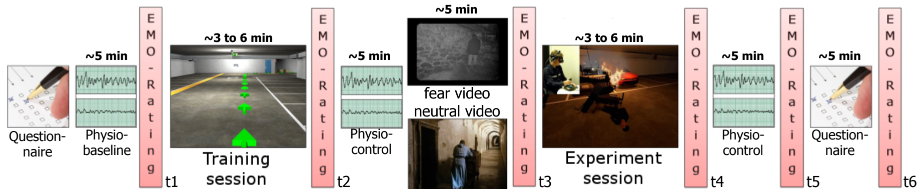


Fig. 2: Overall design of the empirical study

by pushing and pulling the joystick, respectively. Leaning the joystick left or right results in sidesteps, whereas turning it slightly to the left or right makes the participant turn accordingly. Finally, as long as "button B" is being pressed the participant's character is "crouching". "Button A" enables participants to take an object or a tool, the latter being either a spray can during training or a fire extinguisher during the experimental session. While holding an object, pressing "button A" again results in dropping it. With just a tool (or nothing at all) in his or her virtual hands the participant opens and closes doors or pushes buttons by pressing "button A." By pressing the joystick's "fire button," the participants throw an object or use a tool. During the training sessions, for example, they are instructed to practice using a tool by coloring a wall with a spray can. Subsequently, they have to throw it away pressing "base button C."

The setup of the physiological sensors for measuring skin conductivity, heart rate variability, and breath rate are detailed elsewhere [18, 16]. Both sessions of the experiment took place in a darkened room with only the joystick emitting some light for reference. A desktop monitor was used for online questionnaire assessment before, between, and after the experimental sessions.

**Software setup** Valve's Source Engine as was chosen as a software framework following similar work by Smith & Trenholme [19]. In addition to their simulation system, we also modified the source code of the Source 2007 engine to include tools such as a spray can and a fire extinguisher and to implement mechanisms for synchronizing the in-game events with the external sensor recordings for later analysis. In addition, we designed an underground parking lot from scratch that features signs, doors, stairways, elevators, cars, and additional models such as a coke vendor machine to make it look most convincingly[3].

## 4 Study design

The overall design of our study can be split up into five parts (cp. Fig. 2). First, socio-demographical and psychometric data as well as previous experience with computer games and VR technology are acquired through questionnaires.

[3] Videos of the final setup can be found here:
`https://www.becker-asano.de/index.php/research/videos/49-videos1#COVE`

Physiological baseline data is recorded for five minutes, followed by a first rating of felt emotions. Then, participants are guided through a training session. A second rating of felt emotions is acquired afterwards; cp. Fig. 2, $t_2$. After a control of the physiological measurement the participant either watches a neutral video clip (control) or a fear inducing video clip (experimental manipulation). Both are around five minutes long and the latter is a clip taken from the movie "Blair Witch Project." Then, at $t_3$, the participants rate their feelings again. The experimental session starts with the participant standing in front of the elevator on the ground, see Section 4.1. After the VR experiment, at $t_4$, the participant has to rate his or her felt emotions again. Finally, the physiological measurement is being controlled again, after which the participants have to rate their emotions once more ($t_5$). After a final questionnaire they are asked to report one last time on their felt emotions ($t_6$).

The training sessions start on underground level five of the parking lot and are acoustically guided both to get used to the control interfaces as well as to the situation they are supposed to deal with.

### 4.1 Experimental session

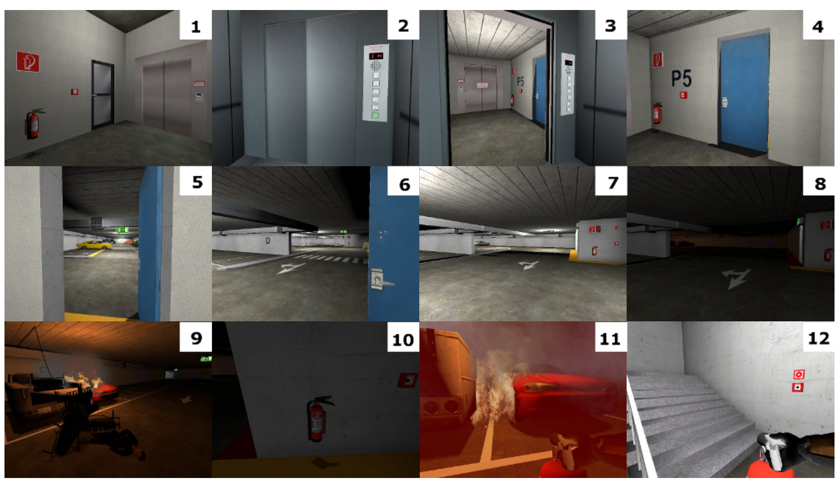


Fig. 3: The experiment session between $t_3$ and $t_4$ (see main text for explanations)

The experimental session starts with the participant on the ground floor inside the same virtual parking lot as the one used for training. The participants are instructed to go down by the elevator back to their red sports car and drive it out of the parking lot. The individual way of reacting to challenging situations might show differences in the participant's emotional skills. Therefore the participants had no further instructions but to react adequately in any situation they might get into. The most appropriate way to deal with the sudden explosion (cp. Fig. 3, #7–8) is to approach the sports car (#9) with the injured person in front of the fire, then, to get back to press the alarm button and to take a fire extinguisher (#10) to extinguish the fire (#11). Finally, it is best to exit the parking lot taking the stairs (#12).

## 5 Experiment results

The outlined experiment was approved by the University's ethics committee. A total of 48 university students participated in the study after they had provided informed consent. Seven of them had to be excluded due to technical errors and/or missing data. The remaining 41 participants (age: $M = 23.4$ years, $SD = 3.1$ years, 18 male, 23 female) were randomly assigned to the experimental conditions, with 20 watching the neutral movie clip ("control condition", 5 male), and 21 the fear inducing movie clip ("fear condition", 13 male).

### 5.1 Procedure and previous results

We concentrate our analysis on two different data sets, first, the emotion ratings, which were acquired through a visual analogue scale ranging from zero to ten, and, second, the head movement data. Ratings of felt intensity for the emotions fear, anger, shame, sadness, happiness, boredom, guilt, and stress were gathered a total of six times during the course of the experiment; cp. Fig.2. Only the ratings for fear and stress that followed the movie-based emotion induction, i.e. $t_3$ through $t_6$, are included in the analysis, because before the emotion induction at $t_3$ no between groups difference can be expected.

A previous analysis of the physiological data of 20 participants, all of whom belonging to the control condition, showed that heart rate (HR) and skin conductance level (SCL) varied significantly [18]. The mean values of both physiological parameters were higher during the training session (SCL: $M = 8.74$, $SD = 1.83$; HR: $M = 76.21$, $SD = 11.12$), than during the neutral movie (SCL: $M = 8.09$, $SD = 1.19$; HR: $M = 74.54$, $SD = 11.88$), and highest during the minute following the sudden explosion in the experimental session (SCL: $M = 9.16$, $SD = 1.82$; HR: $M = 88.47$, $SD = 13.44$). Thus, the general emotional arousal significantly increased during the virtual emergency as compared to both the training session and the neutral movie.

### 5.2 Analysis of emotion ratings ($RQ_1$)

Two repeated-measures ANOVAs with time (from $t_3$ until $t_6$, four levels) as within-groups factor and condition (fear versus control, two levels) as between-groups factor were performed for fear and stress.

For fear the main effect of both condition, $F(1, 152) = 1.21$, n.s., and time, $F(3, 152) = 1.84$, n.s., remained below the desired five percent level of significance. Also, no significant interaction effect was found, $F(3, 152) = 0.69$, n.s.

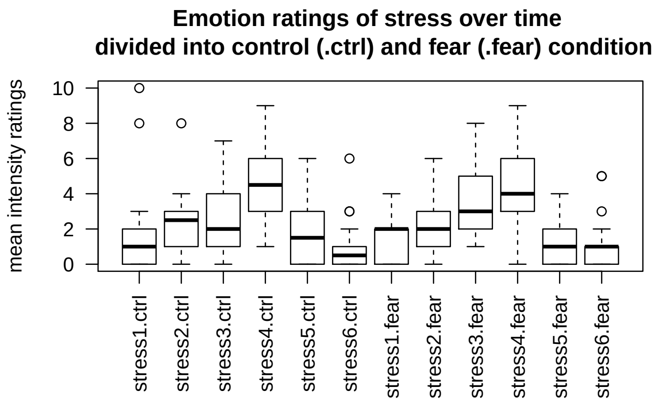


Fig. 4: The questionnaire results for "stress" compared between conditions

The repeated-measures ANOVA of the stress ratings, in contrast, showed a significant main effect for time, $F(3, 152) = 4.255$, $p < 0.01$, but, again, not for condition, $F(1, 152) = 0.37$, n.s.; cp. Fig. 4. No significant interaction effect was found, $F(3, 152) = 1.27$, n.s. A post-hoc paired t-test (bonferroni corrected) revealed a significant increase ($p < 0.01$) of stress levels from before the experimental session (stress3, $M = 3.02$, $SD = 2.04$) to just after this session (stress4, $M = 4.51$, $SD = 2.33$), and a significant decrease ($p < 0.01$) from just after the experimental session to after the third baseline (stress5, $M = 1.54$, $SD = 1.45$); cp. Fig.4.

### 5.3 Analysis of head movements ($RQ_2$)

Pitch values along the sagittal and yaw values along the horizontal plane of every participant were recorded with a sampling frequency of approx. 60 Hz during both the training and the experimental session. The yaw values are a combination of turning the joystick and looking around with the HMD, whereas the pitch values are only changing in relation to HMD (i.e. head-) movements. Accordingly, these two data streams are preprocessed and analyzed independently.

To investigate $RQ_2$ two consecutive 15 seconds intervals from just before ($B_1$ and $B_2$) and another two consecutive 15 seconds intervals from immediately after ($A_1$ and $A_2$) the sudden explosion during the experimental session are analyzed (cp. Fig. 3, #8). Nearly all participants were still waiting for the elevator doors to open (cp. Fig. 3, #3) 30 seconds before the explosion(cp. Fig. 3, #8). After the explosion none of the participants reached the injured person depicted in frame #9 of Fig. 3 within 30 seconds. The features extracted from the corresponding pitch and yaw data streams are subjected to two separate within-subject, repeated-measures ANOVAs.

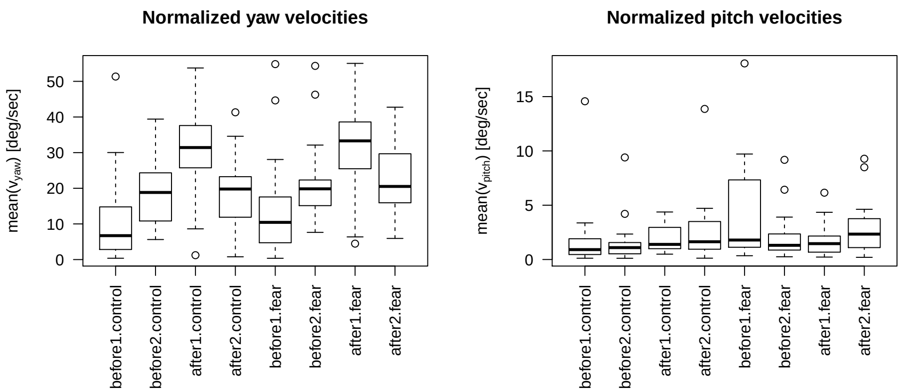


Fig. 5: Average, absolute pitch (left) and yaw (right) velocities of the 15 seconds intervals immediately before and after the explosion compared between conditions

**Preprocessing and feature extraction** We preprocessed the raw head-movement data as follows to remove noise:

1. A small number of consecutive values with the same timestamp due to measurement delays are deleted.
2. Turns above 180 degrees or below -180 degrees are corrected by adding or subtracting 360 degrees resp. to/from all subsequent data.
3. A low-pass butterworth filter with cut-off frequency 0.9 Hz is applied to eliminate noise.
4. Applying the primary difference quotient resulted in a sequence of velocities $v_{pitch/yaw}$ in degrees / sec.

The mean of the absolute values of pitch and yaw, respectively, are calculated as features $f_{pitch/yaw}$ per participant and data set.

**Results** Mean pitch and yaw velocities are plotted in Fig. 5. Although the previous analysis indicates only a weak effect of the experimental variation, for completeness the two conditions are included as between-groups factor in the following two repeated-measures ANOVAs in addition to time (four levels) as within-groups factor.

The repeated-measures ANOVA of the average pitch velocities showed no significant main effect for time, $F(3,150) = 0.266$, n.s., but, a main effect for condition, $F(1,150) = 4.564$, $p < 0.04$.; cp. Fig. 5, right. A post-hoc pairwise t-test, however, reveals that the difference between fear-group ($M = 2.73$, $SD = 3$) and control-group ($M = 1.96$, $SD = 2.45$) is not significant ($p > 0.07$). The interaction effect was not significant either, $F(3,150) = 1.76$, n.s.

The repeated-measures ANOVA of the average yaw velocities, in contrast, showed a significant main effect for time, $F(3,150) = 3.135$, $p < 0.03$. For condition, however, the main effect is not significant $F(1,150) = 2.1$, n.s.; cp. Fig. 5, left. Again, no significant interaction effect was found, $F(3,150) = 0.155$, n.s. A post-hoc paired t-test (bonferroni corrected) reveals a significant increase of average yaw velocity from $B_1$ ($M = 12.57$, $SD = 13.18$) to $B_2$ ($M = 19.98$, $SD = 10.75$; $p < 0.4$) and from $B_2$ to $A_1$ ($M = 31.52$, $SD = 13.26$; $p < 0.01$). Subsequently, from $A_1$ to $A_2$ ($M = 20.87$, $SD = 9.68$; $p < 0.01$) the average yaw velocity decreased significantly to a level similar to that just before the explosion occurred.

## 6 Conclusions

We set out to search for correlations between a human player's emotional arousal and his or her head movements while having to cope with a virtual emergency ($RQ_2$). In addition, we checked whether our video-based method of emotion induction was effective ($RQ_1$), which seemed only to be the case for stress, but not for fear.

A significantly higher average horizontal head movement speed, however, was found that might be interpreted as an immediate response to a sudden, stressful event. In the light of results derived previously from physiological data analysis, these findings suggest that increased physiological arousal might, in general, be correlated with faster horizontal head movements.

A number of challenging questions remain for future research, such as (1) do further features extracted from the acquired physiological data support the conclusions drawn with regard to $RQ_2$, (2) how can we better detect and account for inter-individual differences in head movement profiles, and (3) which other scenarios might be implemented to address these questions?

In summary, if emotional arousal indeed results in a change of head movement speed, then our results seem to indicate that this kind of arousal is of rather short duration. Already fifteen seconds after the unexpected events the average movement speed returned to the same level as just before the event.

## Acknowledgment

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