Towards Voluntary Pupil Control
Training Affective Strategies?

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Abstract: During the past years, increasing attention is being paid to operationalize pupil dynamics for affective classification (Jacobs, 1996). Thereby it is generally assumed that pupil size displays a genuine impression of user's cognitive state but defies any voluntary control (Loewenfeld, 1993). Based on Ekman (2008) we applied graphical feedback on pupil diameter changes to utilize mechanisms of operant conditioning to gradually enable voluntary control over pupil size. Participants underwent a training program to exert control by utilizing affective associations to expand pupil size and relaxation strategies to reduce it. As a result, more than half of the participants demonstrated to be able to increase pupil sizes relative to baseline recordings. Training effects did not show up. Furthermore, controlling influence diminishes after about ten seconds. Intentional increase of sympathetic activity seems to be subject to habituation processes that allow central inhibition of parasympathetic pathways only over a short period. Beside strategy-based factors, physiological mechanisms like baseline pupil activity may determine inter-individual differences in exerting voluntary control. In summary it can be noted that pupil-based communication in HCI extends affective monitoring and may constitute an active input channel to reliably interfere by means of simple cognitive strategies.

1 INTRODUCTION

In the history of psychological research, pupil size usually served as a metric of affect or mental effort (Hess 1972; Janisse, 1974). However, due to the complexity of the autonomic system, affect is hard to measure and can't be predicted with perfect reliability. This is aggravated by the fact that pupil size also appears to be influenced by several other factors like motor responses (Simpson, 1968) or sensory stimulation (Loewenfeld, 1966). Hyönä (1995) suggests that the associated dynamics are related to both, cognitive and affective information. It is therefore critical to ascribe changes in pupil diameter exclusively to emotional processing. Still, controlled studies of the recent past refer to pupil size as an adequate information channel that provides insight into the affective state of the user (Partala, 2003).

During the last years, increasing attention is being paid to operationalize pupil dynamics for affective classification, even in the traditionally rational concept of man-machine interaction (Jacobs, 1996). One main objective behind this inclusion is to reduce the high amount of accidents and errors in civilian workplaces that are causally attributed to impairments resulting from increased stress, sleep deprivation, cognitive overload or a combination of these factors (Yu, 2007). Also, the automotive industry is interested to expand the already good laboratory registration (Palinko, 2010) on real environmental conditions. Thereby it is generally assumed that size and responsiveness of the pupil display a direct and genuine impression of the user's affective and cognitive state but defy any voluntary control (Hess, 1972; Loewenfeld, 1993).

Classical biofeedback paradigms externalize covert physiological responses (e.g. heart rate, skin conductivity or various brain-wave patterns) by providing visual or auditory online-feedback to allow strategy-based interference for the purpose of health preservation or to communicate in affective human-computer frameworks (Meichenbaum, 1976; Bersak, 2001). Until recently, these parameters were considered to be an involuntary response; however, the generation of perceptual awareness led to successful operant conditioning within all these physiological functions. Like the aforementioned, pupil dynamics are regulated by the autonomic nervous system. Still, the vast majority of studies

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refer to pupil responses as a passive information channel that defies voluntary control.

With the present study, the view that pupils function merely as an uncontrollable expression is put into question. Initial results of Ekman (2008) suggested that pupil dilation can be suspect to training. Based on these findings, we applied graphical real-time feedback to externalize the covert muscle response and evaluated strategy-based cognitive attempts to achieve voluntary control over pupil dynamics. Preliminary data showed that several participants were able to control their pupils (Ehlers, 2014).

A key question is whether systematic training gradually increases the ability to control pupil dilations. Such an adjustment to imagined scenarios would challenge the concept of pupillary responses as passive input variables. The capacity of willful influencing, however, would make the pupil-based framework susceptible to basic principles of operant conditioning. Pupillary information would no longer constitute a true measure during affective monitoring; on the contrary: progressively exploring the cause-and-effect relationship between physiological parameters (arousal, valence, cognitive load) and dependent changes of a system's status may trigger the user's need for self-efficacy and open a channel for strategy-based interventions and voluntary control.

Pupil Dynamics

Size and responsiveness of the human pupil is at any time determined by the interplay of two antagonistic muscle groups, governed by the parasympathetic and sympathetic nervous system. Compared to the pupillary sphincter, the dilator muscle exerts a much smaller force; however, this modulation results in a dynamic equilibrium of pupillary size. An increase in sympathetic activity is characteristically accompanied by central inhibitions of parasympathetic activity and leads to an enlargement of pupil diameter. In contrast, low autonomic arousal usually correlates with a reduction in pupil size (Lowenstein, 1963).

Accordingly, larger pupil expansions during the presentation of emotionally negative and positive sounds compared to neutral conditions can be observed (Partala & Surakka, 2003). In particular, they report an onset of pupil dilation at about 400 ms and a gradual increase up to four seconds after stimulus onset.

Voluntary Control

There is, as far as we know, only few research on the possibility of voluntary control of pupil reactions. Ekman (2008) indicate that pupil behavior can be influenced intentionally by strategies of affective regulation or cognitive processing. They report pupil size changes up to 20 % due to various strategies of self-induced emotions, cognitive tasks, physical activity and mild forms of pain.

Preliminary studies of our group also show that pupil dilation can be voluntarily controlled (Ehlers, 2014). However, we assume the true potential of pupil size-based mechanisms in HCI to be considered only when certain aspects of iteration and training are taken into account. That is, we examined the question of whether and to what extent voluntary pupil reactions can be trained. Participants had to consult various strategies known to have modulatory effects on pupil behavior, including positive/negative imaginations and individual relaxation strategies. During training, graphical real-time feedback was applied to externalize the covert muscle response and to enable mechanisms of operant conditioning for gradually achieving voluntary control over pupil size.

2 METHODS

2.1 Stimuli and Apparatus

Pupil diameter of both eyes was recorded using a SMI iViewX Hi-Speed Eyetracker working at 500 Hz with binocular tracking. In order to facilitate control of pupil dynamics, graphical real-time feedback was presented on a grey screen (1680x1050 pixels at 60Hz) in a distance of 65cm (lum= 48cd/m2; approx. 5.5°visual angle). The feedback scheme disentangles task-irrelevant variations (divergences beyond one standard deviation around baseline) from task-relevant variations (see Fig. 2). Performance during baseline calibration was displayed as a static black (mean) against a grey (standard deviation) circle. The current pupil size (red circle) was reported back in real-time.

Real-time feedback was provided according to the single-value approach as specified in Ehlers (2014) and Georgi (2014, *submitted*). This calculation model is based on findings in Bremner (2012) who studied the correlation between amplitude and peak velocity of pupil constriction to the light reflex. Results showed a mean amplitude of 1.92 mm (SD: 0.39) and an average peak velocity of 5.65 mm/sec (SD: 1.17).

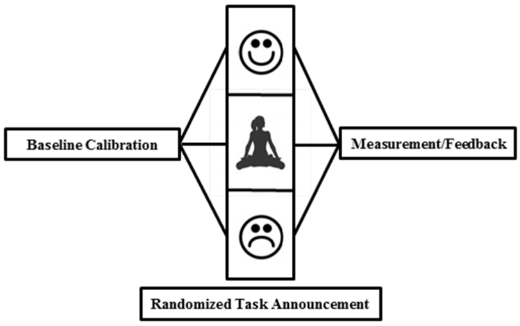

Figure 1: Instruction pictograms for self-induced positive (upper) and negative (lower) imaginations and the relaxation task (middle).

For the current implementation the reported peak velocity is used as a limit for detecting (un-)valid measurements. Converting the specifications to our sampling rate of 30 Hz leads to an allowable sample-to-sample change of 0.1883 mm. If the distance between two values exceeds this range the latest measurement is substituted by the last valid value. Blink artefacts are rejected, and a valid pupil contraction at the outset is detected. Still, the dynamics subsequent to the first blink are rejected as well. Pre-tests showed that constantly received feedback on the basis of untreated values leads to shaky expansion movements of the feedback circle that are difficult to handle. As a consequence, the last two forwarded values are averaged to smooth the feedback dynamics and ensure increased usability.

2.2 Training Procedure

Every participant passed an introductory session (test run) to carefully choose for individual task-specific strategies and to initially test them with regard to the anticipated effect. Participants were instructed to improve their voluntary control by utilizing affective associations to expand pupil size and by consulting relaxation strategies to reduce it. In the following weeks, participants underwent a training program including four consecutive sessions with no more than four days in between. Accordingly, the current within-subjected design with repeated measurements compensates for the comparable few subjects by sustainable reducing secondary variances; however, the experimental set-up is still characterized by a low external validity.

Each training session consisted of three trials; two auto-suggestion tasks (negative and positive thoughts) and the relaxation period. Trials were carried out in randomized order. As Janisse (1974) suggested, pupil size is linearly related to the intensity dimension of the stimuli and behaves curvilinearly on the valence scale with largest expansions at the negative and positive ends. Participants were therefore encouraged to utilize affective autobiographical memories and to maintain a selected approach during the envisaged training procedure. The same applied for the individually designed relaxation strategies. Baseline recording preceded every trial (Tab. 1).

Table 1: Testing procedure.

Test run	1st Session	2nd Session	3rd Session	4th Session

Session (randomized)		
Trial 1 (Negative)	Trial 2 (Relaxation)	Trial 3 (Positive)

Trial	
Baseline (15 sec)	Measurement (30 sec)

Each trial consisted of establishing a baseline and a subsequent experimental phase. Winn (1993) points out that the pupil continuously undergoes small oscillations and that a single „snapshot“ estimate of its size cannot be accepted as a reliable predictor of the true mean; it should rather be monitored for a suitable period. We applied 15 seconds of baseline recording to enable a reliable estimate of mean pupil size and standard deviation.

During baseline recording participants were instructed to avoid any emotionally charged imaginations. Subsequent measurement time was set to 30 seconds. Subsequent to baseline recording a pictogram indicated the respective task (Fig. 1). Subjects were encouraged to immediately induce negative/positive imaginations after indicating trial starts via button-presses. The subjects could therefore determine the duration of rest periods between single (randomized) trials to avoid carry-over effects as a result of previous affective associations.

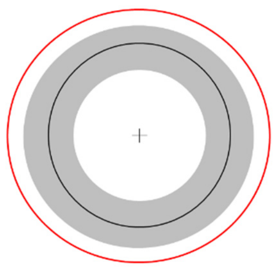

Figure 2: Feedback scheme (Ehlers, 2014).

2.3 Participants

A total of ten participants (eight female; mean age: 21.8 years; SD: 2.5) were included in the present study. One participant's data had to be excluded due to technical errors during data acquisition. All participants were right-handed and had normal or corrected-to-normal vision. Participants reported no history of head injury and no neurological or psychiatric disorder. No participant was taking any kind of medication during the period of testing.

3 RESULTS

3.1 Effects of Training

Due to the sample size of n=9 and deviations in sphericity, determination of statistic values followed the non-parametric paired sample Mann-Whitney-U-Test for comparing means over the 30 seconds measuring time.

Figure 3 depicts the grand-averaged signal course of pupil diameter for all subjects within the first and last session of training. Participants were instructed to utilize real-time feedback for operant learning and to enlarge pupil size using affective associations. Since arousal (and far less valence) seems to constitute the influencing variable on pupil enlargement (Partala & Surakka, 2003) and since we did not observe differences between positive and negative imagination trials, we forego the separation of results and present findings as a mean outcome of affective interventions in general. Dynamics are pictured relative to individually determined baselines. Baseline mean is set to zero; the dotted lines illustrate limits of the averaged standard deviations.

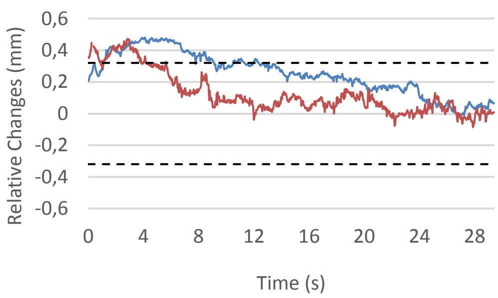

Figure 3: Grand-averaged course of pupil dynamics during the attempt to voluntary increase pupil size via self-induced positive/negative emotions. Data points averaged across all trials of training session one (blue line) and four (orange line) (n=9). Signals depict variations from baseline mean (set to zero; averaged standard deviations dotted).

Compared to baselines, self-induced associations led to a trend of increased pupil diameters already during the first session of training but solely within the initial ten seconds (Fig. 3, blue line; Baseline mean: 5.11, SD: 0.68; Measurement mean for 30 seconds: 5.49; SD: 1.16) (T(9) = -1.9; p = .06). Subsequently, pupil sizes decline and remain on the level of spontaneous fluctuations. A similar tendency can be observed in session four (orange line); however, deviations from baseline do not longer emerge statistically significant. Thus, an overall effect of training could not be established.

Figure 4 illustrates the grand-averaged signal courses during the attempt to voluntary decrease pupil diameter by utilizing individually designed relaxation strategies. The blue line depicts mean dynamics during the first session of training, the orange line traces the averaged course of session four. Though self-induced relaxation seems to be associated with a linear decline of pupil size, values do not fall below spontaneous variations (dotted lines).

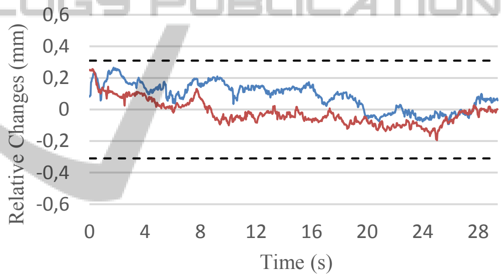

Figure 4: Grand-averaged course of pupil dynamics during the attempt to voluntary reduce pupil size via individual designed relaxation strategies. Data points averaged across all trials of training session one (blue line) and four (orange line) (n=9). Signals depict variations from baseline mean (set to zero; averaged standard deviations dotted).

3.2 Grouping of Subjects

Ekman (2008) report large variability between subjects in the general ability of controlled interference as well as huge variations in magnitude of the effect. Crider (1971) report individual differences with regard to the habituation of skin conductance responses (SCR) and spontaneous fluctuations in skin resistance. Both variables have been used to define a trait called "electrodermal lability" which exhibits high retest-reliability and reflects inter-individual differences within a variety of information processing tasks. Subjects with high rates of spontaneous fluctuations and/or slow SCR habituation are referred to as electrodermal "labiles"; in contrast to electrodermal "stabiles" with only few fluctuations and/or fast SCR habituation. Individual distinctions within physiological reactions or habituation to (endogenous) stimuli correspond to our basic question and we will hereafter try to apply this concept on pupillary dynamics.

With regard to the assumptions outlined above, we inspected the current sample in view of inter-individual differences. It became apparent that five out of nine participants were consistently (throughout all trials of the complete training period) able to utilize auto-suggestive strategies and voluntary control pupil dynamics with regard to the anticipated effect (here: expansion of size beyond one standard deviation from baseline mean). In contrast, the other four subjects were either incapable of any intentional influencing in any session, revealed only a one-time accidental success, or produced contrary patterns.

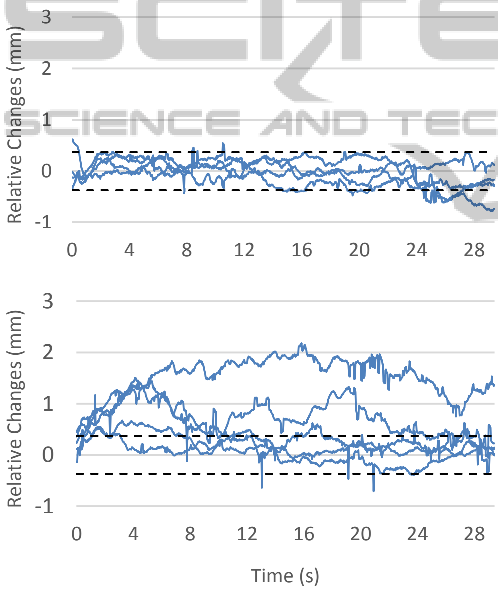

Figure 5: Course of pupil dynamics for "poor performing" (upper illustration) (n=4) and "performing" subjects (lower illustration) (n=5) during the attempt to increase pupil size via self-induced positive/negative emotions. Mean values averaged across all trials of the four training sessions. Signals depict variations from baseline mean (set to zero; averaged standard deviations dotted).

Applying the strict criterion of consistent success (divergences beyond one standard deviation from baseline in every trial of every sessions) on group formation results in the separation depicted in Figure 5. The upper illustration outlines the averaged courses of individual pupil size variations for poor performers (n=4) during strategy-based intervention. The lower figure exhibits mean values for participants successfully exerting voluntary control over pupil size. As can be inferred, intervention via emotionally charged imaginations leads to increased pupil sizes only for the "performers". However, even an exclusive analysis of the successful subjects did not reveal a clear effect of further improvements during training sessions.

Figure 6 depicts the grand-averaged course of pupil dynamics for both groups, whereas data points are averaged across all four training days. Again, due to increased pupil diameters during the first ten seconds we encounter significant higher values for the group of "performers" (blue) ($T(9) = -1.96$, $p = .05$). In both groups pupil sizes decline during the last two thirds of recording and fall back on baseline level.

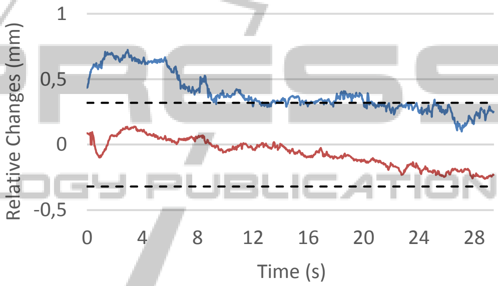

Figure 6: Grand-averaged course of pupil dynamics for "poor performing" (orange) and "performing" subjects (blue) during the attempt to increase pupil size via self-induced positive/negative emotions. Data points averaged across all four training sessions. Signals depict variations from baseline mean (set to zero; averaged standard deviations dotted).

In contrast to group effects recorded during self-induced emotional associations which result in increasing pupil size, we did not discover any performance differences with regard to the attempt to voluntary decrease pupil diameter. Both groups failed to exert intentional influence.

3.2.1 Baselines

According to Crider (1971) individually marked electrodermal characteristics may serve as a predictive variable for the performance in a variety of information processing tasks. In accordance, we investigated spontaneous pupil behaviour during the 15 seconds of baseline recording to explore for group-specific differences in the underlying physiological characteristic.

Figure 7 shows the averaged baselines preceding the measurement of self-induced affective trials for all participants. As can be seen, the group of performing subjects (blue) exhibits higher values in pupil diameter compared to the poor performing participants (red). However, this trend was not of statistical significance (T(-1,22); p = .28).

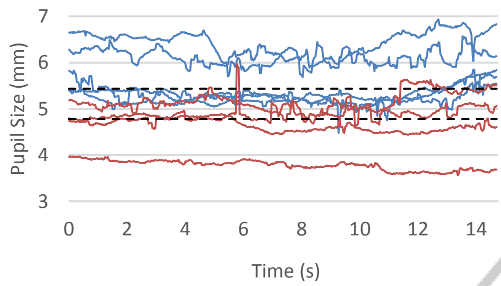

Figure 7: Individual courses of baseline data (averaged over all sessions) preceding the trials of voluntary affective interference for "performing" (blue) (n=5) and "poor performing" (red) (n=4) subjects.

4 CONCLUSIONS

Based on findings of bio-feedback on various physiological variables (Meichenbaum, 1976; Bersak, 2001), effects of voluntary control over pupil reactions were assessed in a training study. Five out of nine participants demonstrated to wilful increase their pupil sizes relative to baseline recordings. Training effects did not show up, at least not over the current period of four weeks and not even within the well performing subjects. This latter group slightly tends to exhibit larger pupil sizes already during baseline recording.

The present study demonstrates that voluntary controlling pupil responses is possible; at least for about half of the participants. Probably, this behaviour requires intuitive feedback on pupil size changes providing adequate support for control and facilitating the opportunity of intentional influencing in pupil-based frameworks. But still, some participants were not capable of exerting wilful control, not even after weeklong training. Beside strategy- or feedback-based factors it seems obvious to discuss physiological mechanisms of action determining the observed inter-individual differences. However, due to the complexity of the autonomic nervous system that mediates bodily states of arousal, group distinctions may arise from a multitude of different reasons. Though we discovered only a weak trend at this point, poor performing subjects featured slightly smaller pupil sizes already during baseline recording. Further investigations with larger samples may establish this trend. It would, however, be reasonable to assume that smaller pupil sizes are accompanied by a decrease in sympathetic tone which indicates a lower level of arousal. Such a reduced activity may limit the ability for spontaneous self-induced changes between affective states. Again, the current sample does not permit to test for psychometric constructs, e.g. to consider whether the outlined physiological characteristic correlates with reduced trait anxiety. Norris (2007) reports increased and prolonged deflections in skin conductance to affective stimuli for subjects who score high on the neuroticism scale. Such a factor may act as a confounding psychological variable that could prevent participants with lower values from utilizing fear-laden imaginations to the same extent as anxious subjects.

Partala & Surakka (2003) find significantly larger pupil size dilations in response to both, negative and positive stimulation compared to neutral auditory stimuli. They report pupil dynamics following a predetermined course with an increase at about 400 ms after stimulus onset and a plateau phase up to four seconds followed by a slow decrease. Visual inspection of the signal characteristics within our performing subjects reveals an almost identical course, displaying a slope during the first second and a continuing dilation until about six seconds after button-press. These similarities emerge despite the varying methodological concepts. The stimulus-driven design should provoke a phase-locked reaction with high degree of inter-trail stability. In contrast, the current paradigm consulted a response-locked approach and is subject to blurred effects due to the individually generated onset of self-induced autonomic activation. As a consequence, participants were encountered to immediately induce negative/positive imaginations after indicating trial starts via button-presses. However, though a true starting point of the endogenous response could not be determined, it can be stated that voluntary pupil dilations follow a similar temporal sequence compared to time-locked reactions. Furthermore, performing subjects achieved twice the relative pupil resize due to self-induced activation as reported for stimulus-related changes (Partala, 2003).

Successful participants were able to expand pupil diameter repeatedly and reliably beyond the range of spontaneous fluctuations. Still, even for good performing subjects, the controlling influence diminishes after a period of about ten seconds. These findings are in accordance with initial results provided by Ekman (2008). Intentional increase of sympathetic activity via self-induced affective associations seems to be subject to habituation processes that allow central inhibition of parasympathetic pathways only over a short period of time. Ekman (2008) reports pupil size expansions over a corresponding time length, even though as a result of combined strategies (e.g. physical activity, self-induced pain, focusing gaze). The current results indicate a comparable outcome to be already achieved on the sole basis of auto-suggestive strategies.

Naveteur (2005) shows that physiological reactions to anxiety-related imaginations are not universal equal across different subjects. Improved coping strategies may provoke lower activity in fearful participants compared to less anxious subjects. With regard to the current issue, fear seemed particular useful since it evokes the greatest pupil expansion of all specific emotions (Al-Omar, 2013). Cacioppo (2000) consistently states that feelings of anxiety lead to a stronger increase in physiological activity compared to various forms of happiness. However, we did not find considerable differences between self-induced autonomic activation arising from positive or negative thoughts. This is in line with reports from Partala & Surakka (2003) who recorded no deviant pupil courses to stimulation with negative and positive auditory stimuli.

Still, the unspecific strategies within the current study may constitute a methodological deficit. During training of pupil dilations via self-induced negative imaginations, subjects consulted individualized autobiographical associations such as fear, grief or fury. While fear is closely related to sympathetic activity, grief may involve a decrease of arousal (Fredrickson, 2000). Reports from our subjects indicate that, among others, personal mourning experiences were consulted. It should therefore be presumed that countervailing effects were produced within the range of self-induced negative associations.

In contrast to the findings mentioned above, results with regard to voluntary pupil constrictions are unequivocal. A systematic reduction in size could not be observed. It is conceivable that the demands of a relaxation task may increment sympathetic arousal and produce physiological response patterns that counter attempt parasympathetic inhibition. Conversely, the feedback of successful pupil dilation may cause an additional increase of autonomic excitation and further reinforce the effect. However, the inability to voluntary constrict pupil size is in accordance with findings from Loewenfeld (1966) who studied the effects of various sensory and psychological stimuli to pupil dynamics and agreed that none of them caused pupil constriction except increased light intensity. Biofeedback paradigms utilizing heart rate variations report similar findings. Sakakibara (1994) observed that slowing down heart rate is more difficult to accomplish than learning to increase cardiac rhythm. Achieving low states of arousal in laboratory conditions in which participants have to continually monitor and process feedback information appears therefore possible only to a limited extent. However, Laeng (2013) reports subjects to voluntary adjust their eye's pupils to imaginary light; a corresponding instruction may therefore constitute a more suitable strategy to apply voluntary pupil constriction.

Against the backdrop of these outstanding issues it is mandatory to explore and evaluate further pupil parameters sensitive to task- or individual-specific differences. Applying the concept of electrodermal "labiles" and "stabiles" (Criter, 1971) to pupil dynamics may serve to further validate the depicted group-specific distinctions and comprise the opportunity to conceive a similar typology that determines individual reactions to affective stimuli. However, preliminary findings within a second test series challenge a purely physiologic explanation approach of the observed differences in performance. Stricter requirements with regard to the adopted strategy (e.g. no associations of grief during self-induced negative imaginations) seem to bring out clearer results and a considerable effect of training.

In summary, it can be noted that pupil-based communication in human-computer frameworks extends affective monitoring by far. If the required conditions for operant learning are available, the pupil constitutes an active input channel that allows several users to reliably interfere by means of simple cognitive strategies. Further studies will demonstrate whether pupil-based interference solely contaminates passive user observation or may even be consulted as an autonomous input option.

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REFERENCES

Al-Omar, D., Al-Wabil, A. and Fawzi, M. (2013). Using Pupil Size Variation During Visual Emotional Stimulation in Measuring Affective States of Non Communicative Individuals. In Stephanidis, C. (Ed.), *Universal Access in Human-Computer Interaction. User and Context Diversity* (pp. 253-258). Berlin: Springer.

Bersak, D., McDarby, G., Augenblick, N., McDarby, P., McDonnell, D., McDonald, B. and Karkun, R. (2001). Intelligent Biofeedback Using an Immersive Competitive Environment. In Abowd, G. D., Brumitt, B. and Shafer, S. (Eds.), *UbiComp 2001-Lecture Note in Computer Science* (Vol. 2201). Heidelberg, Germany: Springer.

Bremner, F. D. (2012). Pupillometric Evaluation of the Dynamics of the Pupillary Response to a Brief Light Stimulus in Healthy Subjects. *Investigative Ophthalmology & Visual Science*, 53, 7343-7347.

doi: 10.1167/iovs.12-10881.

Crider, A. and Lunn, R. (1971). Electrodermal Lability as a Personality Dimension, *Journal of Experimental Research in Personality*, 5, 145-150.

Ehlers, J., Georgi, J. and Huckauf, A. (in press). Improving Voluntary Pupil Size Changes for HCI.

Ekman, I., Poikola, A., Mäkäräinen, M., Takala, T. and Hämäläinen, P. (2008). Voluntary Pupil Size Change as Control in Eyes Only Interaction. *Proceedings of the 2008th Symposium on Eye Tracking Research & Applications*, 115-118.

Fredrickson, B. L., Mancuso, R. A., Branigan, C., and Tugade, M. M. (2000). The Undoing Effect of Positive Emotions. *Motivation and Emotion*, 24(4), 237-258.

Hess, E. H. (1972). Pupillometrics. In Greenfield, N.S. and Sternbach, R.A. (Eds.), *Handbook of Psychophysiology* (pp. 491-531). New York, NY: Holt, Rinehart & Winston.

Hyönä, J., Tommola, J. and Alaja, A. M. (1995). Pupil Dilation as a Measure of Processing Load in Simulataneous Interpretation and Other Language Tasks. *The Quarterly Journal of Experimental Psychology*, 48(A), 598-612.

Jacob, R. J. K. (1996). The Future of Input Devices. *ACM Computing Surveys*, 28, 177-179.

Janisse, M. P. (1974). Pupil Size, Affect and Exposure Frequency. *Social Behavior and Personality*, 2, 125-146.

Laeng, B. and Sulutvedt, U. (2013). The Eye Pupil Adjusts to Imaginary Light, *Psychological Science*, 27.

doi: 10.1177/0956797613503556.

Larsen, J. T., Berntson, G. G., Poehlmann, K. M., Ito, T. A. and Cacioppo, J. T. (2000). The Psychophysiology of Emotion. In Lewis, M. and Haviland-Jones, J. M. (Eds.), *Handbook of Emotions* (*2nd ed.)* (pp.173-191). New York, NY: Guilford Press.

Loewenfeld, I. E. (1966). Comment on Hess' Findings. *Survey of Opthalmology*, 11, 291-294.

Loewenfeld, I. E. (1993). Anatomy and Physiology. In Loewenfeld, I. E. and Lowenstein, O. (Eds.), *The Pupil: Anatomy, Physiology, and Clinical Applications* (pp. 498-510). Iowa City: Iowa State University Press.

Lowenstein, O., Feinberg, R. and Loewenfeld, I. E. (1963). Pupillary Movements During Acute and Chronic Fatigue *Investigative Ophthalmology & Visual Science*, 2(2), 138-157.

Meichenbaum, D. (1976). Cognitive Factors in Biofeedback Therapy. *Biofeedback and Self-Regulation*, 1(2), 201-216.

Naveteur, J., Buisine, S. and Gruzelier, J. H. (2005). The Influence of Anxiety on Electrodermal Responses to Distractors. *International Journal of Psychophysiology*, 56(3), 261-269.

Norris, C. J., Larsen, J. T. and Cacioppo, J. T. (2007). Neuroticism Is Associated with Larger and More Prolonged Electrodermal Responses to Emotionally Evocative Pictures. *Psychophysiology*, 44(5), 823-826.

Palinko, O., Kun, A.L., Shyrokov, A. and Heeman, P. (2010). *Proceedings of the 2010th Symposium on Eye-Tracking Research & Applications*, 141-144.

Partala, T. and Surakka, V. (2003). Pupil Size Variation as an Indication of Affective Processing. *International Journal of Human-Computer Studies,* 59, 185-198.

doi: 10.1016/S1071-5819(03)00017-X.

Peavler, W.S. (1974). Pupil Size, Information Overload, and Performance Differences. *Psychophysiology*, 11(5), 559-566.
doi: 10.1111/j.1469-8986.1974.tb01114.x.

Sakakibara, M., Takeuchi, S. and Hayano, J. (1994). Effect of Relaxation Training on Cardiac Parasympathetic Tone. *Psychophysiology*, 31(3), 223-228.

Simpson, H. M. and Paivio, A. (1968). Effects on Pupil Size of Manual and Verbal Indicators of Cognitive Task Fulfilment. *Attention, Perception, & Psychophysics*, 3(3), 185-190.

Winn, B., Whitaker, D., Elliott, D. B. and Phillips, N. J. (1994). Factors Affecting Light-Adapted Pupil Size in Normal Human Subjects. *Investigative Ophthalmology & Visual Science*, 35(3), 1132-1137.

Yu, M., Kautz, M. A., Thomas, M. L., Johnson, D., Hotchkiss, E. R. and Russo, M. B. (2007). Operational Implications of Varying Ambient Light Levels and Time-Of-Day Effects on Saccadic Velocity and Pupillary Light Reflex. Ophthalmic and Physiological Optics, 27(2), 130-141.
doi: 10.1111/j.1475-1313.2006.00450.x.