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A relationship between operator performance and arousal in assembly

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Abstract

In order to meet the challenges of future complex systems, manufacturing companies need to better understand how social sustainability affects the operator. One way of studying this is to investigate the possible relationships between operator performance and emotion in an assembly experiment. 60 participants took part in an experiment to investigate the relationships between operator performance and objective and subjective arousal. Results showed a weak relationship between operator performance and objective arousal but no significant relationship was found between performance and subjective arousal. The relationships indicate that further studies on operator emotion could be important to better assembly performance. A tool for doing this might be the Qsensor used in this experiment (measure of objective arousal). More studies are needed to further investigate found relationship and if objective emotion measures can be used to predict performance at assembly workstations.

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Keywords: Operator performance; arousal measurement, assembly; perceived view.

1. Introduction

A prerequisite for the success of modern manufacturing companies is the ability to produce as effectively as possible. This demands a high degree of flexibility and re-configurability of the production system [1], which introduces complexity to the systems. In these systems, human operators remain an invaluable resource; by being superior to robots at rapidly interpreting unplanned tasks and situations and handling flexibility and complexity [2, 3]. In recent years there has been an increased need for social sustainability research regarding operators' working conditions [4, 5]. Assembly operators are human beings with moods, emotions and subjective experiences that influence their communication, decisions, actions and motivations regarding both work and personal life [6]. If operators experience dissatisfaction and negative feelings towards their assembly work tasks, manufacturing companies face the risk of losing employees to competitors. Negative feelings such as boredom and under-stimulation affect operator performance [7]. To stay competitive and avoid costly personnel turnover as well as knowledge draining in the future, manufacturing companies therefore need to be mindful of the well-being and subjective emotions of their employees.

By studying *operator emotions* connected to the task or system it is possible to detect stress, anxiety and frustration among the operators, as well as boredom [8]. Individuals are also diverse and have different knowledge and skills in their work situation and will therefore often experience work-related stress when the work demand is not matched with their own abilities [9, 10].

To stay competitive and avoid costly personnel turnover as well as knowledge draining in the future, manufacturing companies need to be mindful of the well-being and subjective emotions of their employees. It is therefore important to study operator emotion in order to improve the working conditions, which can have positive impacts on performance. Previous performed experiments show that operator performance can be increased by introducing changes to the information presentation [10, 11]. In these

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experiments, information presentation was changed according to the operators' errors and perception of the situation.

This paper presents a correlation study of that experiment. The aim of this paper is to investigate if there are correlation relationships between operator performance and arousal. Operator emotion is studied by looking at subjective and objectively measured arousal.

1.1. Operator emotion

In traditional cognitive science, emotions were not seen as essential to human cognition and were in fact explicitly disregarded in the study of the human mind (e.g. [12]. However, in later years, and especially with the widening of the cognitive scope to include a more context aware view of human cognition, this disregard for emotions has been heavily criticized and emotions are now seen as a crucial element of human cognition (e.g. [13-15]). Damasio argues for a dichotomy of emotions and feelings where the former are closely coupled with the neurobiology of the brain as basic, conscious or unconscious and involuntary states such as hunger, fear or pain. He further argues that feelings are the phenomenological experiences of emotions [14].

When studying operators' emotions, understanding the nature of emotion and how it is assessed, is important. Individual difficulties in assessing and describing one's own emotions have been noted by many researchers [16]. These difficulties suggest that emotions lack distinct borders, which makes it hard for individuals to discriminate one emotion from another. However, subjects rarely explain one positive emotion without mentioning their experience of other positive emotions [17]. Posner et al., note that emotions are complex and have overlapping experiences [18], similar to the experience of colours where some colours look alike and are interrelated. This indicates correlations between different emotions which researchers address by dimensional models of affect [18].

Schlosberg divided emotion in a two-dimensional model, pleasantness-unpleasantness and attention-rejection by studying facial expressions of emotion [19]. Later, the dimensions were developed and remade into different models by different researchers, but with similar concepts [18]. Russell proposed a structured model of affect states [20], which included the two dimensions of emotion: arousal and valence. Smiling and laughing are behaviours related to valence described by bipolar adjectives such as happy/unhappy and pleasant/unpleasant. Arousal is portrayed in an individual's activity and alertness, galvanic skin response and by scales such as wide-awake/sleepy and excited/calm [21]. The dimensions are visualized in Figure 1 [18, 20] where arousal is on the vertical axis and valence on the horizontal axis. Arousal is depicted on a scale from aroused to not aroused or not engaged independent of whether the emotion is positive or not and valence is ranging from unpleasant to pleasant.

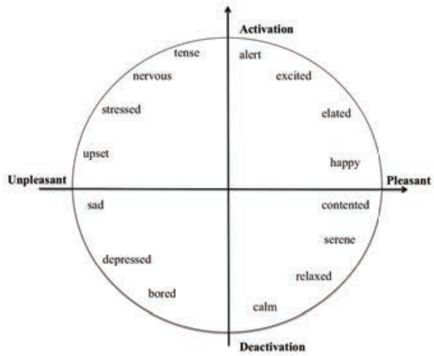

Fig. 1. Russell´s Circumplex Model of emotion [18].

Furthermore, some researchers argue that a third dimension is needed to describe affect [21, 22]. These researchers provide evidence that supports the three-dimensional model, which includes dominance in addition to the two dimensions stated above. Stamps tested both the two- and three-dimensional models of affect and results indicated that the three-dimensional version is the beneficial model for describing affect [22]. Mehrabian and Russel (1974) define dominance as to what extent an individual feels free to act or is unrestricted. Bipolar items such as autonomous/guided and in control/cared-for may be used to measure this concept. This variable is maybe not as obvious as the others. Whether someone is happy or aroused is easier to address and not as abstract as noticing when someone is feeling dominant.

In this study, SAM was used to measure the subjective experience of emotion (regarding arousal, valence and dominance). SAM is an assessment scale based on pictures that indicate the levels of arousal, valence and dominance. The assessment is based on an individual's affective reaction to stimuli. SAM was originally implemented as an interactive computer program, and was later expanded to include a paper-and-pencil (PPSAM) version for use in groups and mass screenings [23]. In this study, *subjective operator emotion* is measured using PPSAM self-ratings. Figure 2 illustrates the PPSAM used in the experiment. The figures represent the self-assessed valence (first row ranging from unhappy to happy), arousal (second row ranging from relaxed to excited) and dominance (third row ranging from little control to control).

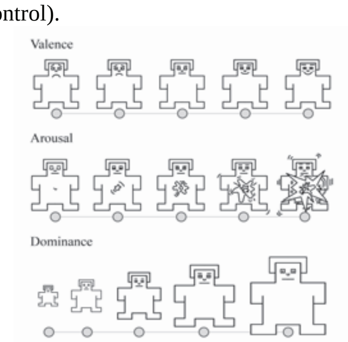

Fig. 2. The Self-Assessment Manikin (SAM) used in the experiment to measure the subjective emotion of valence (first row), arousal (second row) and dominance (third row). To the original figures, explanatory text in Swedish was added [23].

Changes in emotion, motivation, habits and attitude have been successfully investigated by studying the changes in the sympathetic branch of the Autonomic Nervous System (ANS) [24, 25]. This has been done by looking at Skin Conductance (SC) which is a measure of the Electro Dermal Activity (EDA) to measure human arousal, attention and cognitive effort [24]. EDA is the electrical changes that occur when the sweat glands in the skin area are activated [25] and a peak EDA can mean that something is very engaging (positive in valence) or that something is very stressful (negative in valence). The measurement is made using sensors and gives a continuous, objective data set. This has been proven especially useful in relation to studying user satisfaction, as well as real-time affect assessments of the Human-Automation Interface [25]. As the sensors are both cheap and can be measured reliably [24], the method can easily be conducted. The application of SC measures is market research (like for instance customer emotion and usability testing), clinical research to predict seizures for autistic children and studying for instance alcoholism, post-traumatic stress but also to study other areas like online gaming, learning and artistic expression [26]. This measurement is especially interesting because it can show otherwise hidden processes reflecting, for instance, how people make decisions [24]. According to the appraisal theory, cognitive appraisal is the mental process of interpreting and attaching meaning to sensory stimuli, which is a prerequisite for evoking emotional response [27]. The appraisal that underlies emotional response is often unconscious [28]. EDA signals can provide information about an emotion before it is conscious to the participant, and thereby preceding a reaction [29]. EDA measures have also been used to discriminate stress from cognitive load [30, 31].

EDA however does not measure one exact emotion but serves as a general indicator for arousal, attention, habituation, preferences and cognitive effort [24, 25]. Since ANS-signals can be due to reactions to the situation (noise in background, people walking by) and not to the task itself there is also a difference between participants being passive and active during a measurement [24, 25]. If a person is active like for instance giving a speech, the ANS results could be connected to the action of giving a speech (physiological changes while talking, producing a higher voice) and not the physiological response to the situation. Therefore, the EDA needs to be carefully analysed and the experiments should be carried out in a highly controlled manner.

In this study, *objective operator emotion* of arousal is studied by measuring EDA using the Qsensor (developed by Affectiva [26], see Figure 3).

Fig. 3. Skin conductance sensor indicating objective arousal

The sensor output is a curve, (see curve example, Figure 4). This will give a general index of anxiety or arousal connected to that situation [26]. The peaks of an EDA measure can be investigated by calculating the number of Non-specific Skin Conductance Responses (NSCR) per minute. In this experiment three types of peaks are measured: up-peaks, flat peaks and down-peaks.

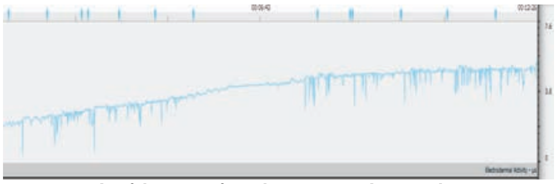

Fig. 4. An example of the output from the Qsensor indicating objective arousal. The curve comes from the experiment, which shows activation (first assembly) then a less peaking area, then another assembly.

When emotions are communicated they are often connected to situation and historic contexts [18]. Figner et al., state that even though it is hard to distinguish the valence of an emotion, this is often given by the situation or can be included through self-report measures such as rating scales [24]. In a study of cognitive processes in air traffic control [32], frequency scales and subjective ratings were used instead of observations. It is important to cross-validate information since work done is many times automatic (the operators have learned the station work so well that they don't consciously think about what they are doing) Since the ratings could be a subjective reconstruction more than a real-time explanation [32]. Participants were therefore also asked how they perceived the situation.

1.2. Operator performance

A common way to define performance is to describe it either in terms of quality [33] or in terms of manufacturing/technical performance. Quality can be defined as a measure of the total qualified production volume that can be achieved by the actual production system during the considered period [34]. Technical performance can instead be defined as the obtained quantity of qualified products at the output of the system, i.e. process and operator performance. Each of these quality measures is a partial quality measure and is integrated to form a total quality measure [33]. Other researchers believe that a combination of productivity and quality should be used as a performance measure when designing a production system [35, 36]. Further merit to this argument is given by the observed negative correlation between the two e.g. [37].

In this paper, *operator performance* is measured by counting the correctly assembled parts, i.e. studying the technical performance. Operator performance was measured by counting the Number of Parts Assembled Correctly (NPAC) studying photographs taken of the assembly parts (video recordings captured unexpected events).

2. Experimental approach

60 participants were recruited primarily via campus message boards at Chalmers University of Technology and were undergraduate and graduate students. Participation was voluntary and each participant was observed separately. The

participant data can be seen in Table 1. The experiment took approximately 30-40 minutes to complete. Participants were given cinema tickets to increase the amount of participants and also to increase their commitment. The experiment was pilot tested several times before final deployment.

Table 1 Participant data for the participants in the experiment

Participant characteristics	Participant data
Number of participants	60
Percent Male/Female (No.)	52%(31), 48%(29)
Average age	22.3 years
Last time assembling Lego	8-15 years 58% 4-7 years 8% 1-3 years 10% 1-3 months 10% Recently (days-weeks) 8%
Education department (descending order)	Machine engineering 50% Automation and Mechatronics 27% Other 23%
Education level (descending order)	Bachelor level 86% Master level 10% Other 4%

The experiment was a repeated measures design (two assemblies) and the equipment consisted of a conveyer belt in a fixed position, the material façades, as well as two tablets showing the cycle time (see Figure 5). The participants assembled a gearbox out of Lego in two different cycle times, 50 seconds (cycle time A) and 70 seconds (cycle time B), five times each. Half the participants started with cycle time A and half started with cycle time B as their 1st assembly.

Fig. 5. Experiment setting, material façade and Lego product to assemble.

The experiment consisted of five different phases and a combination of qualitative and quantitative methods were used, as illustrated in Figure 6.

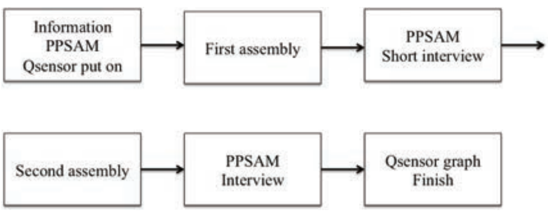

Fig. 6. Phases in the experiment and the different methods used for analysis and measurement of the results.

First, the participant filled in basic information such as age, experience of Lego assembly, and education and completed a first round of the PPSAM. Before, between and after the two assembly intervals the operator filled in a PPSAM form regarding their emotions, and was also interviewed concerning overall thoughts about the assembly. The participant was then given a description of the experiment. The Qsensor was worn during the entire assembly. The operator also got to see the arousal graph after each assembly interval, to help analyse it. To understand the assembly situation, participants were asked how they felt, after the two assemblies.

To test the correlation between performance and arousal (both subjective and objective) two-tailed Pearson's tests of correlation were performed (two-tailed since the distributions are considered to be normal). The test is used to find statistical dependence between two variables (assumed to be linear. The correlations are measured from -1 to + 1; the closer the correlation coefficient is to ±1, the stronger to correlation is. When describing the strength of a relationship correlation the following is often used: .00 no relationship, ±.3 weak relationship, ±.5 moderate relationship, ±.7 strong relationship and ±1.0 exact relationship [37].

3. Results

3.1 Operator performance and subjective arousal

Six two-tailed Pearson's tests of correlations were performed to measure the relationship between each variable of subjective emotion and its corresponding variable of operator performance (NPAC A for cycle time A or NPAC B for cycle time B). Adding the results from PPSAM from before and after the assemblies (cycle time A separated from cycle time B) six variables represented an individual's arousal, valence and dominance for each of the cycles. None of the correlations were significant.

3.2 Operator performance and objective arousal

The relationship between operator performance and objective arousal was tested by studying peaks (NSCR/min): peak up, flat and down peak. It was seen that the top six operators had a doubled performance but also had double the amount of flat and down peaks (per minute, see Table 2). The number of up peaks were more frequent, M(top 6) = 42.14 compared to M(bottom6) = 31.32.

Table 2: Comparison of number of peaks for the top and bottom 6 NPAC

NPAC	NPACtotal	Up peaks/min	Flat peaks/min	Down peaks/min
Top6	168.83	42.14	6.88	134.83
Bottom6	79.83	31.32	2.43	68.72

When tested statistically (using two-tailed Pearson's test of correlation) one significant correlation was found. It was seen that for the 1st assembly a weak/moderate positive relationship was seen for NPAC and flat peaks $r(45) = 0.43$ ($p < .01$, see Fig 7). No other significant correlations were seen.

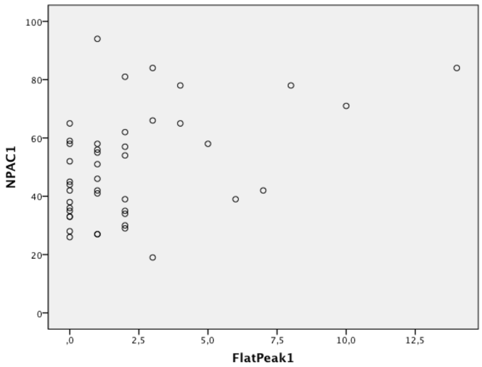

Fig. 7: Relation between number of correct assembled parts and flat peaks/min in the 1st assembly

3.3 Perceived situation

In general the 1st assembly was perceived as stressful (*M*=4.8) and difficult (*M*=3.4) while the 2nd was seen as better (*M*=4.2) or even much better. In the 1st, assembly participants (cycle time order AB) said that it was stressful (*M*=47) and good (*M*=3.3). The 2nd assembly was mainly said to be better (*M*=5.7). Participants starting with the longer cycle time BA said instead that the 1st assembly was stressful (*M*=5.0) and difficult (*M*=4.5) and that it then was stressful (*M*=4.5).

4. Discussion

The aim of this paper was to investigate if relationships between *operator performance* and arousal could be found. Results showed one significant correlations: a weak/moderate correlation between NPAC in 1st assembly and the number of flat peaks. The results could be due to do deactivation i.e. calmness (see Fig. 1) and that operators in the 1st assembly had to concentrate to be able to learn and handle the situation (thereby producing flat-peaks). Some support is seen in the interviews (perceived situation) where operators in general said that the 1st assembly was stressful, difficult and good, and the 2nd assembly was perceived as better. The reason for not having a stronger correlation could be because the Qsensor does not measure emotion but instead serves as a general indicator for arousal, attention, habituation, preferences and cognitive effort [24, 25]. The changes in arousal could also depend on other performance shaping factors like hunger, fatigue and stress etcetera [7] or on the situation it self. Factors affecting the operator performance and emotion could be cognitive ability (to read instructions, understand situation), previous emotion (in a real industrial environment) or the ability to resist stress.

Although the experiment setting does not reflect an industrial assembly station the results might be useful in an industrial setting. Investigating subjective emotions in industry is difficult since self-ratings and interviews take time from the valuable production; therefore the observed correlations between operator performance and objective arousal is important. Measuring objective emotion, using small devices producing real-time data, points towards the possibility of measuring emotion in a simpler manner, which does not disrupt production.

Future work includes further analysis of how emotion is connected to performance. Due to that both physical and cognitive load are important drivers of complexity in final assembly [38], experimental studies will be performed to study how different load conditions (physical, mental and disturbances) affect arousal.

5. Conclusions

This paper presents a weak relationship between operator performance and objective arousal and results indicate that operator emotions may play an important role in understanding and predicting operator performance. More studies are needed to further investigate the effect of operator emotion.

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