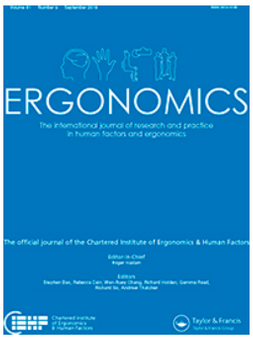

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Development and Validation of a Task Load Index for Process Control Room Operators (PCRO-TLX)

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Abstract

Process control room operators (PCRO) perform a range of complex cognitive safety-critical tasks. The aim of this exploratory sequential mixed methods study was to develop an occupation specific tool to measure the task load of PCRO using NASA Task Load Index (TLX) methodology. Participants were 30 human factors experts and 146 PCRO at two refinery complexes in Iran. Dimensions were developed via a cognitive task analysis, a research review, and three expert panel. Six dimensions were identified: perceptual demand, performance, mental demand, time pressure, effort and stress. Data from 120 PCRO confirmed that the developed PCRO-TLX has acceptable psychometric properties, and a comparison with the NASA-TLX confirmed that perceptual, not physical, demand was relevant for measuring workload in PCRO. There was a positive convergence of scores of the Subjective Workload Assessment Technique and the PCRO-TLX. This reliable tool (α=0.83) is recommended for risk assessing the task load of PCRO.

Keywords: Process industries; human-computer interaction; control room; cognitive workload; information processing

Practitioner Summary

There are benefits of having a specific tool to measure task load in safety critical roles. Thus, we developed and validated an easy-to-use targeted tool, the PCRO-TLX, for process control room operatives. Timely use and response will assure optimal production alongside health and safety in an organization.

Word counts

Abstract: 150 words

Practitioner Summary: 47 words

Main text: 6293 words

Introduction

The use of advanced control and display technologies in modern process control rooms can support efficient and smart production. Human process control room operators (PCRO) are an essential element in a production process and a crucial part of the protective layers of a production process (Das et al., 2018). PCRO are responsible for monitoring, maintaining, and keeping control of all plant through human-machine interfaces. Working effectively and safely with an array of display technologies typically requires rapid sampling and integration of large volumes of information. Thus, the work of a PCRO demands significant perceptual and cognitive abilities to provide a link between stimuli and the required reaction (Schumacher et al., 2011). PCRO need accuracy, high alertness, and the ability to make quick decisions to function correctly, and it follows that these working conditions potentiate a high mental workload. Providing working conditions where there is correspondence between sensory stimuli and motor response without exceeding the limits on information processing systems is an important principle of ergonomics (Wickens, 2008). Critically, if the given workload becomes excessive then performance is negatively affected, and this can manifest as inappropriate slowness, and compromised decision-making when carrying out tasks (Cain, 2007; Ghanavati et al., 2019). Consequently, the need to assess the load imposed on the operator's processing capacity is significant in safety-critical high-tech systems where suboptimal performance can be disastrous (Pretorius and Cilliers, 2007; Tao et al., 2019). Ultimately, optimization of mental workload is imperative to keep pace with technological developments in the workplace (Van Acker et al., 2018).

It is now over 40 years since Moray (1979) published an edited book on the subject of human operator mental workload as a problem area for industry in terms of taking full advantage of developments in human-machine operations. Moray's own chapter initiated a consideration of how to measure such workloads to understand performance. Since then, a review of the mental workload literature (Cain, 2007), observed that there are numerous factors that influence cognitive demands, that it is difficult to precisely measure, but that there remains a strong reason to comprehensively measure the human cost of performing complex mental tasks to assure efficiency, safety and duty of care to employees and the wider public. Ultimately, mental workload is an important predictor of human performance in complex systems (Young et al., 2015). Researchers have presented a gamut of definitions of the nature of mental workload (Longo, 2015), and for cognitive workload - essentially the same construct (Hancock et al., 2021). Probably the most comprehensive definition came from an analysis of 82 separate references to the construct in the theoretical and applied

literature: “Mental workload is a subjectively experienced physiological processing state, revealing the interplay between one’s limited and multidimensional cognitive resources and the cognitive work demands being exposed to” (Van Acker et al., 2018, p.358).

Attention to workplace operations is a fundamental component of the PCRO job. Responding to the mental workload demands requires effort sourced by a capability to draw upon a metaphorical reserve of energy to fuel cognitive processing (Kahneman, 1973). In their conceptual analysis of Kahneman’s resource theory, Bruya and Tang (2018) argued that whilst effort as a mental process is objective, it is unclear whether the subjective feeling of effort is different from objective effort. To the best of our knowledge there is no convincing examination of this assertion. What is certain is that there are intrinsic limits of an operator’s information processing system than can impact on performance (Wickens and Carswell, 2021), and thus measurement of workloads and prediction of task performance is still a key issue for those concerned with human operators working in a safety-critical arena (Dehais et al., 2020).

Ultimately, mental workload is an abstract assessment cannot be directly observed, but it can be inferred though various methods, including performance-based methods, physiological methods, and subjective methods (Chuang et al., 2016). A physiological indicators approach is based on the idea that mental workload causes an increase in metabolic activity in the brain that can be measured. The main attraction of physiological measurements is the continuous and objective assessment of the operator at work (Ntuen, 1998). However, besides the challenge of defining a meaningful increase that is due to cognitive effort from increased cognitive workload (Bruya and Tang, 2018), these methods often require the attachment of sensors, which may lead to physical discomfort and constraints in working. In addition, individual differences make calibration necessary for every single person, which is very expensive due to the time and the trained personnel required to use this method. Finally, there have been two recent reviews of empirical studies that have used physiological measures to investigate their ability to distinguish differences in mental workload. Tao et al (2019) included 91 studies in their analysis of 78 physiological measures. Ayres et al (2021) conducted a review of 33 experimental studies that used physiological measures. In both studies, the authors found that when the complexity of tasks was varied most measures could detect *some* level of difference in mental workload, but overall, the measures were not universally valid for all tasks. Critically, Ayres et al. argued that suggestions that physiological methods would usurp subjective methods for understanding mental workload were premature, and their comparative analysis of the two types of measure generally found a

greater validity for subjective measures of mental workload. Importantly, both studies supported the previous assertion of Charles and Nixon (2019) that measuring mental workload using physiological measurements are challenging and more research is needed in this area.

A subjective assessment is based on the operator's understanding of the workload imposed on them, and the perceived effort they would need to exert to accomplish the task. Mental workload assessment methods reflect an operator's opinion of the effort required for them to perform the task, and this will be influenced by their perceived resources, skills and previous experience of a task (Di Stasi et al., 2011). Despite the tendency to prefer objective methods in ergonomics, subjective methods have been more popular and widespread because they are relatively cheap whilst maintaining simplicity, reliability and good validity (Marras, 2006). It is the case that most workload risk assessments use subjective scales (Matthews et al., 2015) even though concerns of the poor scientific credibility of mental workload as an ergonomic construct, and of instruments that purport to measure it, have been raised (e.g. Dekker, et al., 2010; de Winter, 2014; Matthews et al., 2020). Matthews et al. (2020) presented a disquisition of the theoretical status of 'workload', the variety of ways the construct is understood, the multitude of measures used to assess it, and the challenge of interpreting subjective workload measures that do not line up with objective performance measures. They concluded that there is an urgent need for a resolution of the lack of convergence in subjective and objective evaluations of workload that can be seen across the breadth of the ergonomics and human performance literature. It is a challenge for both pure and applied ergonomics. De Waard and Lewis-Evans (2014) point out that there are parallels between physical workload and mental workload, even though mental workload cannot be quantified by forces in the way that physical workload can. In the same way as physical fitness, training and experience impact on physical workload, so capability, training and experience are important for understanding mental workload. Similarly, the ability of human operators to cope with workload demands according to the *quality* (routine v urgent; simple v complex; novel v experienced; etc.) as well as the *quantity* of work, in a dynamic workplace, involves cognitive decision making that is applied to both physical and mental tasks. Essentially, subjective mental workload can provide suitable and sufficient predictive value for supportive intervention (de Winter, 2014), and "workload scales remain undeniably useful in many applied circumstances" (Matthews et al., 2020 p. 370).

Accepting that the ergonomic construct mental workload and validated scales to measure it are an outcome of pragmatism, it is critical that the measures used are fit for

purpose (de Winter, 2014; Van Acker, 2020). In the absence of a validated scale to measure the task load of PCRO it was important to develop an occupation specific tool to PCRO to be able to foresee excessive mental workload as a precursor to developing interventions. That is, the mental workload tool should meet published criteria related to validity, sensitivity, reliability, and applicability, as well as being unobtrusive and acceptable to the workforce (van Acker, 2020).

The literature already includes a significant number of subjective measures of mental workload. The most common of these are the NASA Workload Index (NASA-TLX) (Hart and Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT) (Reid and Nygren, 1988). The NASA-TLX method has been called the gold standard tool for measuring workload in research involving human-computer interactions (Ayres et al., 2021). The NASA-TLX evaluates more dimensions yet takes less time to execute than the SWAT method, and it also has higher validity and reliability (Rubio et al., 2011). Besides the lengthy card sorting procedure, the principal criticism of the SWAT has been that it is not sufficiently sensitive to low mental workloads (Luximon and Goonetilleke, 2001), which has contributed to the popularity of the NASA-TLX method, and its various modifications (Hart, 2006).

The NASA-TLX method was developed based on the argument that workload is a hypothetical construct and it is the subjective experience of a worker, not simply the objective demands of the work, that contribute to human performance (Hart and Staveland, 1988). The authors identified six dimensions of workload to provide diagnostic information of overall workload: mental demand, physical demand, temporal demand, one's own performance, effort, and frustration after analysing what most people experienced performing most tasks (Hart, 2006). Participants are asked to rate their task demands from 0 to 100 for each of the six subscales (Hart and Staveland, 1988). Due to the generalizability of the NASA method, this method has been used in many studies besides its original area of aviation, and there have been various modifications to both the scale and the scoring (Hart, 2006). For example, the six-dimensional structure of the task load index (TLX) has been retained for assessing the mental workload of drivers called the Driving Activity Load Index (DALI; Pauzi, 2008), as well as the Surgery Task Load Index (SURG-TLX; Wilson et al., 2011). The dimensions of these two scales mapped onto but were different from the 'original' NASA-TLX, to accord with the specific objective demands of being a driver and a surgeon respectively. There is also a 10-dimension version for use in virtual reality simulation training (SIM-TLX; Harris et al., 2020) which includes the six dimensions of the NASA-TLX and extends the assessment with four additional dimensions. Regarding the use of the NASA-

TLX in PCRO, a search provided three peer-reviewed studies. Ghanavati et al. (2019) used the NASA-TLX to examine the level mental workload in PCRO. Of interest, this study illustrated that mental workload was indeed high for PCRO, but in only four of the six dimensions of the PCRO-TLX. Critically, it was evident from their mean rating for the physical demand workload dimension of the NASA-TLX (36.15/100), that this dimension was peripheral to the job demands of PCRO. The authors also specifically discussed the significant contribution of stress and anxiety to the frustration dimension, drawing upon other similar comments in the literature to suggest it was stress that is important to workability. Braarud (2020) similarly found that the six dimensions of the NASA-TLX did not satisfactory measure PCRO workload. They acknowledged that mental workload is a multidimensional construct but suggested that a single dimension was sufficient to represent mental workload in the control room. Similar to the findings of Ghanavati et al, they found limited importance for two of the six dimensions of the NASA-TLX (physical demand and frustration), but despite acknowledging the high scores of effort and time pressure it was argued that the one dimension could efficiently replace the original NASA-TLX. Mohammadian et al (2022) used the NASA-TLX to assess the relationship of 12 specific cognitive demands with mental workload according to control room role (operators and supervisors). Not surprisingly, the results found that cognitive demands and mental workload were significantly positively correlated, as well as levels being high. Interestingly, the results of the Mohammadian et al. study also show that two dimensions of the NASA-TLX (performance and physical demand) were much less relevant to levels of mental workload that the other four dimensions, suggest that the NASA-TLX methodology could be improved for use in PCRO.

From the above discussion we provide a rational for the purpose of this study: to develop a TLX specifically for assessing the workload of PCRO. Despite the great importance of the work in process control rooms (Li et al., 2011), and significant technological developments in this area even in the past decade, no study has yet been conducted to develop and apply a specific method to accurately measure PCRO workload. Thus, the aim of this study was to develop and validate a PCRO-TLX.

Methods

The Scientific and Ethical Committee of Shiraz University of Medical Sciences approved the research project (***IR.SUMS.REC.1398.446***). Following the World Medical Association Declaration of Helsinki – Ethical Principles for research involving human subjects, all

participants were volunteers, all gave written informed consent, and all understood their right to withdraw at any time during the study. No payment was made to any participant.

Design

An exploratory sequential design was used. A participatory qualitative phase was conducted to identify the main areas of mental workload of PCRO. The think-aloud method (van Someren et al., 1994) was used to determine the cognitive demands of the PCRO tasks, supported by a review and analysis of relevant research in scientific databases. Expert panels were then used to guide the development of dimensions. The subsequent quantitative phase investigated the psychometric properties of the developed tool.

Participants

All participants were male. Participants included 30 experts in Ergonomics, Health & Safety, and Cognitive Psychology who were recruited using targeted sampling from Universities and Industry. In addition, using census sampling, all 163 PCRO working in two refinery complexes in Iran were invited to join the study to validate the developed tool. With management support, posters advertising the study were displayed in staff areas, and an email was sent to all PCRO outlining the study and including the approved Participant Information Sheet. Altogether, 146 PCRO gave informed consent. Data was collected during participant's regular work shifts.

Qualitative Phase

Targeted sampling was used to recruit a sample of PCRO with at least five years of work experience from those who volunteered to take part in the study for the task analysis part of the qualitative phase. A sample size of five has been suggested to be sufficient for stable results when using the think-aloud method, although this has also been criticized as insufficient (Lundrén-Laine and Salanterä, 2010). In this study, 11 PCRO with two levels of seniority in the control room were recruited for the task analysis part.

In addition, two Expert Panels each consisting of 15 different participants were formed. Information about the research, and an invitation to join the panel were sent to qualified ergonomists, Health & Safety officers and cognitive psychologists known to the research team. The first 15 to receive an invitation agreed to join the study for both of these Expert Panels. A third Experts Panel represented experienced PCRO. Targeted sampling was used to recruit a sample of 15 PCRO with at least five years of work experience from those who volunteered to take part in the study.

Quantitative Phase

120 PCRO participated in the quantitative study. The mean age (standard deviation) of participants was 31.31 (2.91 years). The mean (standard deviation) of work experience was 4.58 (2.65) years. 81.7% of the participants were graduates, and 18.3% were educated to masters or doctoral level. All statistical analyses of the data were performed using IBM SPSS Statistics 23 software and AMOS version 23 software.

Procedure

Qualitative study

The aim of this study was to develop an occupation-specific TLX, building on the extant literature on measurement of mental workload, thus a review of published multidimensional inventories designed to assess with confirmed reliability and validity mental workload was undertaken to guide decision making. For this purpose, a search of PubMed, Scopus, Google Scholar with keywords 'mental workload', 'subjective assessment', 'subjective measures', 'cognitive workload', and 'logics' was used.

The review yielded five comprehensive questionnaires in the field of mental workload assessment: NASA-TLX; DALI; SURG-TLX, SWAT and the Visual, Auditory, Cognitive and Psychomotor (VACP) workload model (Mitchell, 2000). These measures indicated that 13 unique cognitive domains were used in published mental workload measures. These were: mental demand, physical demand, time pressure, performance, effort, level of frustration, need for attention, perceptual demand (auditory and visual), distraction, stress, complexity, cognitive and psychomotor needs.

Besides the review of extant mental workload measures, an analysis of the work in the process control room at the two refinery sites used in this study was progressed to the point where it was possible to consider the cognitive requirements for each of the tasks identified. Then the think-aloud method (van Someren et al., 1994) was used to determine the cognitive demands of each of the identified tasks and sub-tasks. The 11 PCRO who participated in this part of the study were first provided with the necessary training. Then they were asked to verbalize their thoughts while performing the tasks identified and report what was happening in their minds without deletion or change. Concomitant observations by a researcher provided illustrative field notes. All verbalizations were recorded. In order to use the think-aloud method in a consistent way, the PCRO were encouraged to speak if they fell silent. The researcher reminded participants to speak using the phrase "please continue talking" after a

fixed interval of 15 seconds of silence. Altogether, almost 40 hours of thinking aloud were recorded.

Two researchers independently read through the verbatim transcripts several times and possible mistakes were checked and corrected if necessary. Then, the words, sentences or paragraphs of the participants' statements that contained essential points related to the demands of the job were selected as semantic units, and coding – conversion of semantic units into shorter expressions that express the intended concept – was performed separately. The coding process was reviewed to determine sufficient similarity to provide integrity to the process. Ensuring reliability of judgement-based nominal data is difficult, however we followed best practice by considering the agreement of two independent coders (Cousins and Donnell, 2012). Using the formula (*2m/N1 +N2;* Holsti, 1969) agreement was over 80% which suggests the coding procedure was reliable. The small number of differences were discussed and resolved using the researcher's field notes where appropriate. The Experts Panel of 15 ergonomists met face-to-face in a University meeting room to discuss the findings towards determining the dimensions required for a PCRO-TLX. This Expert Panel met on three occasions, adapting decisions in line with the discussions and evolving information. Consensus was reached that the tool should be comprised of six dimensions.

To determine the content validity of the new six-dimension tool, the second Experts Panel, which included three industrial health and safety specialists, six ergonomists and six cognitive psychologists, met using online methods. This panel was asked to check the grammar, wording and placement of phrases in the appropriate place for each item. Specifically, the experts were asked to examine each item separately for relevance to the context, clarity, and the degree of simplicity. Content validity was evaluated using two criteria, the content validity index (CVI) and the content validity ratio (CVR). According to the guidelines, a CVI of more than 0.79 is appropriate, between 0.7 and 0.79 requires review, and less than 0.7 is unacceptable, and the item should be removed. A good assessment tool should include a minimum CVI average of 0.80 (Polit et al., 2007). To evaluate CVR the experts were asked to assess the degree of necessity of each item (Lawshe, 1975). According to the critical values table based on the number of experts participating in the panel provided by Lawshe, and confirmed by Ayre and Scally (2014), items with a CVR of more than 0.49 are necessary and essential, at a significance level of $p < .05$, and items with a lower CVR are better removed. Finally, the third Experts Panel, which included 15 PCRO, were consulted using online methods, to ensure the proposed PCRO-TLX was sufficiently easy to understand with respect to the work.

Quantitative study

To further assess the psychometric properties of developed PCRO-TLX we conducted a controlled laboratory study to ensure that the subjective data collected by the developed PCRO-TLX was sensitive to different levels of task difficult, as well as reliable and valid. First, following the validated NASA-TLX methodology, PCRO (n=120) were asked to appraise all the tasks they performed in their PCRO role using the final dimensions identified using a visual analogue scale that represented a score from 0 to 100 in 5-point increments. The individual task ratings were then combined to provide a total task load index. (As the PCRO-TLX is specific to this occupation, and the tasks well defined, in line with many other studies (Hart, 2008), the second part of the NASA-TLX, to create a weighting of the dimensions, towards dropping dimensions irrelevant to an individual, was not incorporated into the PCRO-TLX). PCRO were additionally asked to provide other data, including the NASA-TLX. A counterbalancing principle was used, and half the sample completed the PCRO-TLX first, and half completed the NASA-TLX first. Discriminant validity of the PCRO-TLX dimensions in terms of the NASA-TLX could be determined using Spearman's rank correlation coefficient (Rönkkö and Cho, 2022). We expected very high correlations in the four dimensions of the two TLX that were the same or conceptually similar, and low or no relationship in the two dimensions that differed in the two TLX.

Participants were next asked to perform a series of standard n-back tasks in three levels: easy (low load), medium (medium load) and difficult (high load) and use the PCRO-TLX and the SWAT (Reid and Nygren, 1988) at the end of each task to assess their understanding of the mental workload assigned to the task they had just performed. The SWAT was used alongside the PCRO-TLX to consider convergent validity. This scale includes three domains of time load, mental effort load and psychological stress load proposed to explain mental workload. Each domain is rated by three scoring levels: low, medium and high. The ratings are converted to a 0 to 100 interval scale, which allowed the relationship of the two measures of workload to be assessed using Spearman's rank correlation coefficient. The ability of the PCRO-TLX to differentiate the three levels of workload (low, medium, high) was evaluated using Repeated Measures ANOVA.

Confirmatory factor analysis was performed to ensure the structural validity of the PCRO-TLX, using the maximum likelihood method at the covariance matrix of variance level. The indices used to assess the model fit were the chi-square/degree of freedom ratio (χ^2/df), the root mean square of error approximation (RMSEA), the goodness of fit index (GFI) and the adjusted goodness of fit index (AGFI), and comparative fit index (CFI) The

final model was used to measure the fit. Values ≤ 2 for the χ^2/df ratio were considered a good fit. RMSE values less than 0.08 were considered acceptable fit, and less than 0.05 were considered a good fit. GFI and AGFI values greater than 0.8 or 0.9 were considered a good fit. Finally, comparative fitness index values (CFI greater than 0.9) were considered a good fit.

Cronbach's alpha was used to assess the internal consistency of PCRO-TLX. Generally, an alpha coefficient of 0.7 is considered an acceptable threshold for reliability, however, 0.80 and 0.90 are preferred for psychometric quality tools. Also, the correlation between the total dimension-score and Cronbach's alpha coefficient of the tool was calculated separately after removing each item.

Results

Qualitative study

There were two types of role in the process control room: operator and supervisor. There were five main tasks for the operator workforce: shift delivery; refining processes control through a distributed control system; answering telephone calls; response in emergency conditions (process); emergency response (accident). There were four main tasks for the supervisor: coordination for repairs; coordination of start and end of permits; attending meetings and submitting reports to the head of the shift; submitting reports to the head of the relevant unit. The task analysis using the think-aloud method, and inductive content analysis identified codes which could be reduced to 11 unique conceptual codes associated with completing PCRO tasks, including: attention, memory, situation recognition, problem-solving, decision making, perceptual demands (auditory and visual), and stress while working in the control room (operators and supervisors). Most of these mapped onto the 13 dimensions retrieved from the review of published mental workload measures. The first expert panel met three times to reduce conceptual codes identified in the workload analysis in terms of the cognitive dimensions from the research background. Six dimensions were agreed upon as the important dimensions affecting PCRO workload that should be risk assessed in the form of a PCRO-TLX: Perceptual demands (auditory or visual), performance, mental demand, time pressure, effort, and stress. Descriptions of the six dimensions are provided in Table 1.

Insert Table 1 here.

Quantitative Study

The overall results of the PCRO-TLX developmental study, according to dimension are shown in Table 2. High task load was seen in all six dimensions. Table 2 also illustrates the relationship of the dimensions on the PCRO-TLX and the NASA-TLX. There were very high correlations in the three dimensions of two TLX that were essentially the same, confirming they are measuring the same thing, and also a significant relationship of two other conceptually similar dimensions. There was no relationship between the perceptual demands dimension on the PCRO-TLX and the physical demands dimension on the NASA-TLX confirming divergent validity as expected on this dimension.

Insert Table 2 and Table 3 about here

Regarding content validity of the PCRO-TLX: the CVI and CVR for each of the six dimensions are presented in Table 3. Mean CVI values and total CVR of the six dimensions were 0.92 and 0.74, respectively, supporting the content validity of the PCRO-TLX.

Sensitivity of the PCRO-TLX was examined by performing standard n-back task tests. Participants' mental workload mean scores (SD) were in accordance with the three levels of difficulty: easy 8.75(1.84), medium 11.26(2.2), and hard 14.24(2.63). A repeated measures ANOVA showed a significant difference between mental tasks at three levels ($F = 58.7$, $p < 0.001$), and there was a linear relationship between mental workloads at three levels ($r = 0.72$ $p < 0.001$). The results of these tests confirm the sensitivity of the PCRO-TLX.

Convergent validity was assured by the relationship between SWAT scores and the developed PCRO-TLX. There was a positive relationship ($r = 0.73$, $p < 0.001$), meaning the mental workload level measured for each participant in the PCRO-TLX increased alongside the mental workload measured in the SWAT.

Before performing the confirmatory factor analysis, the correlation coefficient between each dimension and the total was examined (See Table 4). The total item-score correlations of all six items indicated that these items have the discriminant power to measure the domains. Therefore, all items entered the confirmatory factor analysis. The initial model showed that the model had an acceptable fit, and all factor loadings were significant. The model fit indices are presented in Table 5.

Insert Table 4 and Table 5 and Figure 1 about here

The confirmatory factor analysis path with standardized factor loadings and the error terms for the PCRO-TLX dimensions are shown in Figure 1. The standardized factor loadings for the dimensions ranged from 0.54 (stress) to 0.90 (time pressure). All loadings were significant ($p < 0.001$). These results indicate very good properties for all six tool dimensions.

Cronbach's alpha coefficient for the whole tool was 0.83 (CI: 95-77.87 = 0.87%). In addition, Cronbach's alpha was acceptable if any of the items were removed (0.77-0.82).

Discussion

In this study we developed and validated a multidimensional workload tool, based on the well-established NASA-TLX, to specifically estimate the workload of PCRO. The new PCRO-TLX comprises six cognitive dimensions, four are conceptually similar to four in the NASA-TLX (performance, mental demand, time pressure, effort), and two are different (perceptual demand, stress). A robust methodology was used at all stages of the development and evaluation of the validity and reliability of the tool. The PCRO-TLX has desirable psychometric properties and provides for the first time, a comprehensive assessment of the workload of PCRO. Moreover, for the first time, there is opportunity, using data from the PCRO-TLX to feed into managing PCRO workload for the benefit of both employees and the business. The data from our study found PCRO report high levels of workload. Adjusting the workload on a PCRO task, as required, will improve performance under both normal and abnormal conditions. This should ultimately lead to safer work and the prevention of accidents – which can sometimes be catastrophic. Li et al. (2011) argued that insufficient thinking has been afforded to the design of process control rooms from the perspective of operators. Certainly, control room systems have become increasingly complex, and the contribution from the human operator to industrial accidents is extremely high (Woods and Hollnagel, 2005). Ultimately, work designers will draw upon emerging evidence in the design of new control rooms, but there will still be a need to risk assess the workload of the human operators.

The NASA-TLX has been successfully used to assess workload in many occupations. It has also been adapted without changing its name (Hart, 2008), and it has been adapted for use in specific occupations as we have done here. We suggest our developmental process was robust and indicative of the benefit to using appropriate dimensions for safety critical jobs such as PCRO. Examination of the tasks undertaken by PCRO are few, however the job analysis of PCRO in nuclear plants (Schumacher et al., 2011) strongly suggested high levels of cognitive workload, as well as auditory and visual perceptual demand, which is not explicitly considered in the NASA-TLX. The few studies that have investigated workload in PCRO include Ghanavati et al. (2019), who used the NASA-TLX in a cross-sectional study to investigate the relationship of workload and work ability in PCRO. They found a high

mental workload in the study population, but also that workload with respect to physical demand was low. This strongly suggested the need for a PCRO specific TLX – which we have developed in this study. In line with the findings of Ghanavati et al. our analysis of PCRO work tasks showed that physical aspects of the job were not an important part of PCRO workload, and similarly, in this sample of PCRO reported relatively low task load in physical demand on the NASA-TLX measure. Instead, perceptual demand (both visual and auditory) was recognized as an important component of workload, and as more important to include in the PCRO-TLX than physical demand. Further support for including perceptual demand in the new TLX for PCRO was seen in participant's ratings of workload in this dimension in our developmental study. Task loads in this dimension were rated highest of all the six dimensions – which all indicated high task load. Critically, the NASA-TLX failed to consider the most demanding aspect of the PCRO role – Perceptual demand (auditory and visual) – which strongly supports the use of an occupation-specific measure for assessing PCRO task load, rather than a more generic TLX. Related to this, visual and auditory cognitive-perceptual domains have been included in two other workload assessment methods we reviewed on the basis of providing an occupation-specific assessment: the driving activity load index (DALI) and the visual, auditory, cognitive and psychomotor (VACP) workload model. Most recently, Harris et al. (2020) included the dimension Perceptual strain to their SIM-TLX. This is a nine-dimension adaptation of the NASA-TLX for simulated training using virtual reality. Again, the scores for physical demands were low, but the authors justify retaining the dimension in the SIM-TLX as a physical component may be important in some simulated tasks.

In the PCRO-TLX the sixth dimension, stress, is also different from the NASA-TLX, in which the sixth dimension is frustration. The expert panel recognized that stress – a component part of the frustration dimension on the NASA-TLX – as more precisely relevant to the workload of PCRO. The significant relationship of participants' ratings of stress and frustration is therefore not surprising. The relationship, however, was not so strong as to consider that they could be measuring the same thing. The absolute value of the correlation co-efficient was low enough to indicate that the two dimensions represent distinct constructs (Rönkkö and Cho, 2022). Reference to the established concept of work-related stress appropriately reflect the arousal resulting from insufficient resources (regardless of type) when doing tasks in the control room. Critically, stress is recognized as a significant issue in terms of performance, presenteeism and sickness absence. Evidence of high levels of stress from a PCRO-TLX assessment should immediately indicate a need for intervention.

Similarly, there are stress dimensions in the DALI, and the SURG-TLX in preference to frustration, and stress is differentiated from frustration in the SIM-TLX (where both are included as separate dimensions). In a review of past studies on stress in the control room, Desaulniers (1997) notes that abnormal and emergency conditions, power plant outages, and start-up activities can all be significant sources of operator stress. There is also consensus in the literature that stress can have detrimental effects on operator performance, further supporting the argument for the occupation specific PCRO-TLX as more relevant than the NASA-TLX for measuring task load in PCRO.

The PCRO-TLX is a subjective assessment tool across six dimensions (presented in Appendix 1). Our participants confirmed it was easy to use to measure their task load with the bipolar scales (low to high / good to poor) and the instructional guidance to allow them to provide a rating of their workload in each of the six areas. To be sure a PCRO is able to provide an inclusive answer for each of the six dimensions guidance, in the form of questions to steer their decision making, is given. For perceptual demands, for example, the guidance asks PCRO to consider the impact of both visual and auditory stimuli in their workplace because both types of sensory information compete for attention – a finite resource (Kahneman, 1973), and because auditory and visual attention sources work simultaneously (Ersin et al., 2021). The same logic applies to performance, stress, and mental demands which are complex dimensions.

Whilst there are real strengths to the robust development of this TLX, we recognize that further investigation of the quality of the PCRO-TLX method is required using data from other samples, and a full profiling across tasks. We recognize that it would have been beneficial to have included a psychophysiological measure alongside the subjective assessment of mental workload, however this was beyond the resources available to us. In the 33 experiments examined by Ayres et al. (2021) they found varying levels of validity in the physiological measures used, and critically that subjective measures had higher levels of validity and sensitivity, leading them to conclude "Our data suggests that it may be premature to abandon subjective methods" (p. 12). Similarly, Tao et al. (2019) review of 91 studies raised several issues associated with the use and effectiveness of physiological measures in the assessment of mental workload. A fundamental problem is that whilst most physiological measures are able to measure changes in mental workload effectively, they were not universally valid across all aspects of workload, and "attempts to summarize the best physiological measures of [mental workload] in certain scenarios and for certain individual had little success" (p 16). In this respect, we suggest that there are clear benefits in using the

quick and easy PCRO-TLX compared to time-consuming and expensive physiological measures for assessing task load.

Further study could include other process industries such as petrochemical industries and power plant industries towards developing norms for the PCRO-TLX as well as providing further confirmation of the psychometrics of the tool. We also suggest the PCRO-TLX can be administered verbally, using a written form, and via an online survey platform. Such options, which will extend the work of this study, should also be explored. It remains that there are criticisms of the TLX approach to measure mental workload, and even whether self-report scales can capture mental workload. Ultimately, there is a need for simple, participatory indicator tools that can appropriately assess workload in control room jobs where high mental workload is reported. Such self-report measures can provide suitable and sufficient predictive value for supportive intervention de Winter (2014), and they are undeniably useful (Matthews et al., 2020).

Conclusions

In this study, for the first time, the workload of PCRO can be assessed using a simple occupation specific tool, directing intervention where necessary. Based on the NASA-TLX, the validated PCRO-TLX also has six dimensions: perceptual demand, performance, mental demand, time pressure, effort and stress, however two dimensions are different from the NASA version, to more appropriately assess the mental task load of the PCRO. More work to improve work design for PCRO can be explored with the use of the PCRO-TLX across process control industries and using on-line administration methods.

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References

Ayre, C. & Scally, A.J. 2014. Critical values for Lawshe's Content Validity Ratio: Revisiting the original methods of calculation. Measurement and Evaluation in Counseling and Development, 47, 79-86. https://doi.org/10.1177/0748175613513808

Ayres, P., Lee, J.Y., Paas, F. & van Merriënboer, J.J. 2021. The validity of physiological measures to identify differences in intrinsic cognitive load. Frontiers in Psychology, 12, 702538. https://doi.org/10.3389/fpsyg.2021.702538

Braarud, P.O. 2020. An efficient screening technique for acceptable mental workload based on the NASA Task Load Index-development and application to control room validation. International Journal of Industrial Ergonomics, 76, 102904. https://doi.org/10.1016/jergon.2019.102904

Bruya, B. & Tang, Y-Y. 2018. Is attention really effort? Revisiting Daniel Kahneman's influential 1973 book *Attention and Effort.* Frontiers in Psychology, 9, 1133. https://doi.org/10.3389/fpsyg.2018.01133

Cain, B. (2007). A review of the mental workload literature. Technical report, Defence Research and Development. Toronto, Canada.

Charles, R.L. & Nixon, J. 2019. Measuring mental workload using physiological measures: A systematic review. Applied Ergonomics, 74, 221-232. https://doi.org/10.1016/j.apergo.2018.08.028

Chuang, C-Y., Lin, C.J., Shiang, W-J., Hsieh, T-L., & Liou, J-L. 2016. Development of an objective mental workload assessment tool based on Rasmussen's skill–rule–knowledge framework. Journal of Nuclear Science & Technololgy, 53, 123-128. https://doi.org/10.1080/00223131.2015.1027156

Cousins, R., & Donnell, C. 2012. Nurse prescribing in general practice: a qualitative study of job satisfaction and work-related stress. Family Practice, 29:223-227. https://doi.org/10.1093/fampra/cmr077

Das, L., Iqbal, M.U., Bhavsar, P., Srinivasan, B. & Srinivasan, R. 2018. Toward preventing accidents in process industries by inferring the cognitive state of control room operators through eye tracking. ACS Sustainable Chem. Eng. 6, 2517-2528. https://doi.org/10.1021/acssuschemeng.7b03971

Dehais, F., Lafont, A., Roy, R., Fairclough, S. 2020. A neuroergonomics approach to mental workload, engagement and human performance. Frontiers in Neuroscience, 14, Article 268. https://doi.org/10.3389/fnins.2020.00268

Dekker, S., Nyce, J.M., Van Winsen, R., Henriqson, E. 2010. Epistemological self-confidence in human factors research. Journal of Cognitive Engineering and Decision Making 4, 27-38. https://doi.org/10.1518/155534310X495573

Desaulniers, D.R. 1997. Stress in the control room: effects and solutions [nuclear power plants]. Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants, 1997.'Global Perspectives of Human Factors in Power Generation'. Orlando, FL, USA. https://doi.org/10.1109/HFPP.1997.624894

De Waard, D. & Lewis-Evans, B. 2014. Self-report scales alone cannot capture mental workload. Cognition, Technology & Work, 16, 289-297. https://doi.org/10.1007/s10111-01400277-z

De Winter, J.C.F. 2014. Controversy in human factors constructs and the explosive use of the NASA-TLX: a measurement perspective. Cognition, Technology & Work, 16, 289-297. https://doi.org/10.1007/s10111-014-0275-1

Di Stasi, L.L., Antoli, A., Gea, M., & Cañas, J.J. 2011. A neuroergonomic approach to evaluating mental workload in hypermedia interactions. International Journal of Industrial Ergonomics, 41, 298-304. https://doi.org/10.1016/j.ergon.2011.02.008

Ersin, K., Gundogdu, O., Kaya, S.N., Aykiri, D., Serbetcioglu, M.B. (2021). Investigation of the effects of auditory and visual stimuli on attention. Heliyon, 7, e07567. https://doi.org/10.1016/j.heliyon.2021.e07567

Ghanavati, F.K., Choobineh, A., Keshavarzi, S., Nasihatkon, A.A., Roodbandi, A.S.J. 2019. Assessment of mental workload and its association with work ability in control room operators. La Medica de Lavaro, 110, 389-397. https://doi.org/10.23749/mdl.v110i5.8115

Grier, R.A. 2015. How high is high? A meta-analysis of NASA-TLX global workload scores. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 59, 1727-1731. https://doi.org/10.1177/1541931215591373

Harris, D., Wilson, M., & Vine, S. 2020. Development and validation of a simulation workload measure: the simulation task load index (SIM-TLX). Virtual Reality. 24, 557-566. https://doi.org/10.1007/s10055-019-00422-9

Hart, S.G. (2006). NASA-Task Load Index (NASA-TLX); 20 years later. Proceedings of the Human Factors Ergonomics Society Annual Meeting, 50, 904-908. https://doi.org/10.1177/154193120605000909

Hart, S.G. & Staveland, L.E. (1988). Development of NASA-TLX (Task load index): Results of empirical and theoretical research. In, P.A. Hancock and N. Meshkati (Eds.)

Human Mental Workload. Advances in Psychology, 52, 139-183. https://doi.org/10.1016/S0166-4115(08)62386-9

Holsti, O.R. 1969. Content analysis for the social sciences and humanities. Reading, MA: Addison-Wesley.

Kahneman, D. 1973. Attention and Effort. EnglewoodCliff, NJ: Prentice-Hall.

Lawshe, C.H. 1975. A quantitative approach to content validity. Personnel Psychology, 28, 563-575.

Li, X., McKee, D.J., Horberry, T., & Powell, M.S. 201. The control room operator: The forgotton element in mineral process control. Minerals Engineering, 24, 894-902. https://doi.org/10.1016/j.mineng.2011.04.001

Lundrén-Laine, H. & Salanterä, S. 2010. Think-aloud technique and protocol analysis in clinical decision-making research. Qualitative Health Research, 20, 565-575. https://doi.org/10.1177/1049732309354278

Luximon, A., & Goonetilleke, R.S. 2001. Simplified subjective workload assessment technique. Ergonomics 44, 229-243. https://doi.org/10.1080/00140130010000901

Marras, W.S. 2006. Fundamentals and assessment tools for occupational ergonomics. CRC Press. https://doi.org/10.1201/9781420003635

Matthews, G., De Winter, J., & Hancock, P.A. 2020. What do subjective workload scales really measure? Operational and representational solutions to divergence of workload measures. Theoretical Issues in Ergonomics Science, 21, 369-396. https://doi.org/10.1080/1463922X.2018.1547459

Matthews, G., Reinerman-Jones, L.E., Barber, D.J. & Abich IV, J. 2015. The psychometrics of mental workload: Multiple measure are sensitive but divergent. Human Factors, 57, 125-143. https://doi/org/10.1177/0018720814539505

Mitchell, D.K. 2000. Mental workload and ARL modelling tools. ARL-TN-161.Aberdeen Proving Ground, M.D., Army Research Laboratory.

Mohammadian, M., Parsaei, H., Mokarami, H., Kazemi, R. 2022. Cognitive demands and mental workload: A Filed study of the mining control room operators. Heliyon, 8, e08860. https://doi.org/10.1016/j.heliyon.2022.e08860

Moray, N. 1979. Models and measures of mental workload. In, N. Moray (Ed.) Mental workload. NATO Conference Series, vol.8. Spriner, Boston, MA. https://doi.org/10.1007/978-1-4757-0884-4_2

Ntuen, C.A 1999. The application of fuzzy set theory to cognitive workload evaluation of electronic circuit board inspectors. Human Factors and Ergonomics in Manufacturing

& Service Industries, 9, 291-301. https://doi.org/10.1002/9SICI1520-6564(199922)9:3<291::AID-HRM6>3.0.CO;2-S

Pauzié, A. 2008. A method to assess the driver mental workload: The driving activity load index (DALI). IET Intelligent Transport Systems, 2008. 2, 315-322. https://doi.org/10.1049/iet-its:20080023

Polit, D.F., Beck, C.T. & Owen, S.V. 2007. Is the CVI an acceptable indicator of content validity? Appraisal and recommendations. Research in Nuring and Health, 30, 459-467. https://doi.org/10.1002/nur.20199

Pretorius, A. & Cilliers, P. 2007. Development of a mental workload index: A systems approach. Ergonomics, 50, 1503-1515. https://doi.org/10.1080/00140130701379055

Reid, G.B. & Nygren, T.E. 1988. The subjective workload scaling technique: a scaling procedure for measuring mental workload. In, P.A. Hancock and N. Meshkati (Eds.) Human Mental Workload. Advances in Psychology, 52, 185-218. https://doi.org/10.1016/S0166-4115(08)62387-0

Rönkkö, M., Cho, E. 2022. An updated guideline for assessing discriminant validity. Organizational Research Methods, 25, 6-47. https://doi.org/10.1177/1094428120968614

Rubio, S., Díaz, E., Martín, J., Puente, J.M. 2004. Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. Applied Psychology, 53, 61-86. https://doi.org/10.1111/j.1464-0597.2004.00161x

Schumacher, S., Kleinmann, M. & Melchers, K.G. 2011. Job requirements for control room jobs in nuclear power plants. Safety Science, 49, 394-405. https://doi.org/10.1016/jssci.2010.10.002

Tao, D., Tan., H., Wang, H., Zhang, X., Qu, X., & Zhang, T. 2019. A systematic review of physiological measures of mental workload. International Journal of Environmental Research and Public Health, 16, 2716. https://doi.org/10.3390/ijerph16152716

Van Acker, B. 2020. Mental workload monitoring in the manufacturing industry: Conceptualisation, operationalisation and implementation. Doctoral Dissertation. Ghent University. ISBN 978-94-6355-438-1

Van Acker, B.B., Parmentier, D.D., Vlerick, P. and Saldien, J. 2018. Understanding mental workload: from a clarifying concept analysis toward an implementable framework. Cognition, Technology & Work, 20, 351-365. https://doi.org/10.1007/s10111-018-0481-3

Van Someren, M.W., Barnard, Y.F., & Sandberg, J.A.C. 1994. The Think Aloud method: A practical guide to modelling cognitive processes. Academic Press, London. ISBN 0-12-714270-3.

Wickens, C.D. 2008. Multiple respources and mental workload. Human Factors, 50, 449-455. https://doi.org/10.1518/001872008X288394

Wickens, CD., & Carswell, CM. 2021. Information Processing. In, G. Salvendy & W. Karwowski (Eds.) Handbook of Human Factors and Ergonomics (5th Ed.). John Wiley and Sons, Inc. ISBN 978-1-119-63608

Wilson, M.R., Poolton, J.M., Malhotra, N., Ngo, K., Bright, E., & Masters, R.S.W. 2011. Development and validation of a surgical workload measure: The surgery task load index (SURG-TLX). World Journal of Surgery, 35, 1961. https://doi.org/10.1007/s00268-011-1141-4

Woods, D.D. & Hollnagel, E. 2005. Joint cognitive systems: Patterns in cognitive systems engineering. Boca Raton. CRC Press. https://doi.org/10.1201/9781420005684

Young, M.S., Brookhuis, K.A., Wickens, C.D., Hancock, P.A. 2015. State of science: Mental workload in ergonomics. Ergonomics, 58, 1-17. https://doi.org/10.1080/00140139.2014.956151

Table 1. PCRO-TLX dimension descriptions

Dimension	**Endpoints**	**Descriptions**
Perceptual demand (auditory or visual)	Low – High	How exhausting are the perceptual demands (auditory or visual) necessary for completing the task? Can you focus on relevant stimuli? To what extent are you distracted by irrelevant stimuli?
Performance	Good – Poor	How successful were you in accomplishing the goals of the task? How satisfied are you with the way you worked in relation to the goals of the task?
Mental demand	Low – High	How much mental demand was necessary for the task? For example – thinking, decision making, calculating, searching, remembering.
Time pressure	Low – High	How much pressure do you feel due to time constraints or demands when doing the task?
Effort	Low – High	How much effort did you have to put in to accomplish the performance required by the task?
Stress	Low – High	How much stress did you feel while conducting the task? This may include fatigue, insecure feelings, anxiety, irritation, discouragement, helplessness

Table 2. Mean (SD) of each dimension on the PCRO-TLX and NASA-TLX (range 0-100) and (non-parametric) correlation coefficients between relevant dimensions (N = 120)

PCRO Dimension	**Mean (SD)**	**NASA Dimension**	**Mean (SD)**	**Spearman's correlation**
Perceptual demand (auditory or visual)	91.57 (25.72)	Physical Demand	53.08 (26.32)	**0.139**
Performance	75.83 (33.64)	Performance	75.42 (32.91)	**0.997****
Mental demand	91.39 (21.85)	Mental demand	91.10 (21.51)	**0.861****
Time pressure	83.48 (28.49)	Temporal demand	74.25 (27.11)	**0.525****
Effort	76.67 (31.15)	Effort	74.54 (32.91)	**0.932****
Stress	80.17 (28.34)	Frustration	66.08 (30.73)	**0.491****

** $p \leq 0.001$

Table 3. Validity of PCRO-TLX dimensions

Dimension	**CVI**				**CVR**
	Proportion	**Simplicity**	**Clarity**	**Total**	
Perceptual demand (auditory or visual)	0.93	0.93	0.93	0.93	0.86
Performance	0.93	0.8	0.93	0.88	0.6
Mental demand	1	1	0.93	0.98	1
Time pressure	0.86	0.86	0.93	0.88	1
Effort	0.93	0.86	1	0.93	0.73
Stress	0.93	0.88	0.86	0.86	0.73

Table 4. Correlation coefficients between each dimension and total dimensions

Dimension	**Corrected correlation dimension with total**
Perceptual demand (auditory or visual)	0.732
Performance	0.542
Mental demand	0.597
Time pressure	0.548
Effort	0.550
Stress	0.501

Table 5. Confirmatory factor analysis model indices

Fit index	**Estimated value**	**Acceptable threshold**
X^2/df	1.32	<5
GFI	0.92	>0.9 or 0.8
AGFI	0.82	>0.9 or 0.8
IFI	0.81	>0.9 or 0.8
RMSEA	0.05	<0.8

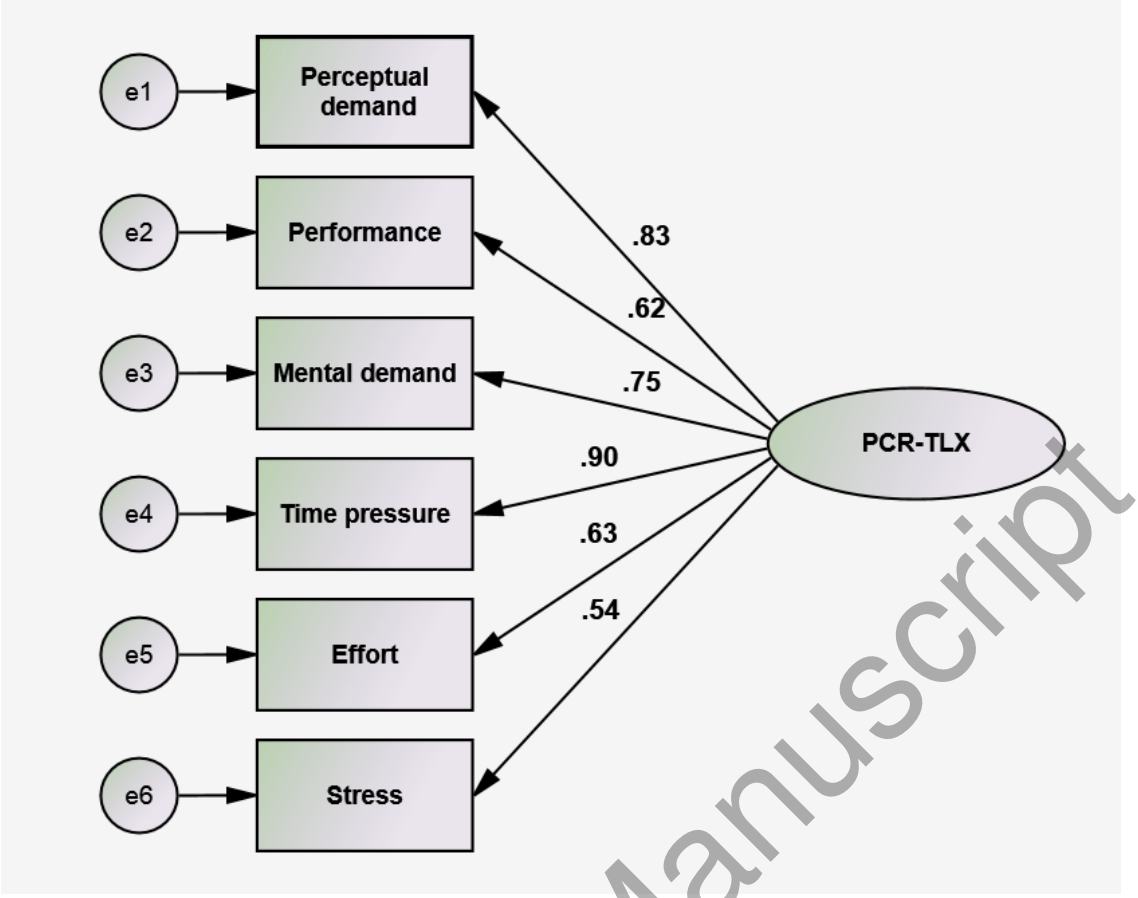


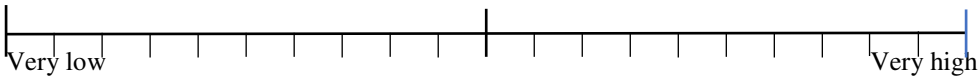
Figure 1. PCRO-TLX measurement model

Figure 1 Alt-Text: Path diagram of the confirmatory factor analysis. The model shows how the six task load dimensions load onto the PCRO-TLX. These are: perceptual demand (.83), performance (.62), mental demand (.75), time pressure (.90), effort (.63), stress (.54).

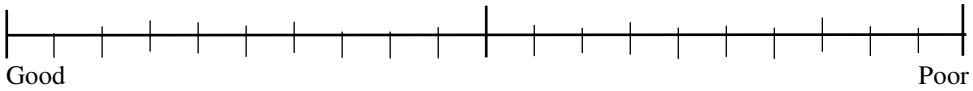
Appendix 1. Process Control Room Task Load Index (PCRO-TLX)

Please mark on the scale your answer to each of the six questions in relation to (TASK NAME)

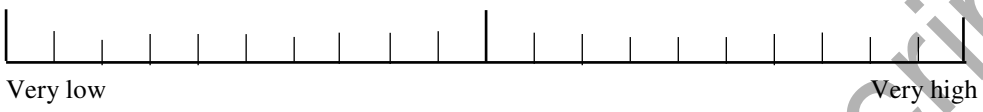
Perceptual Demand (Auditory or Visual): How exhausting are the auditory and visual demands necessary for completing the task? Can you focus on relevant stimuli? To what extent are you distracted by irrelevant stimuli?



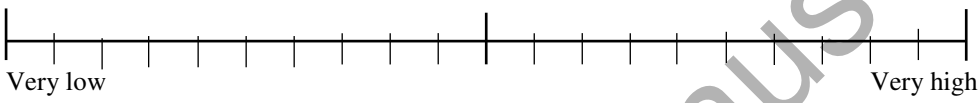
Performance: How successful were you in accomplishing the goals of the task? How satisfied are you with the way you worked in relation to the goals of the task?



Mental demand: How much mental demand was necessary for the task? For example – thinking, decision making, calculating, searching, remembering.



Time Pressure: How much pressure do you feel due to time constraints or demands when doing the task?



Effort: How much effort did you have to put in to accomplish the performance required by the task?

Stress: How much stress did you feel while conducting the task? This may include fatigue, insecure feelings, anxiety, irritation, discouragement, helplessness