Bulletin of the JSME Vol.11, No.5, 2017
Journal of Advanced Mechanical Design, Systems, and Manufacturing

Human-robot collaboration on an assembly work with extended cognition approach

Zeynep USTUNEL* and Tulin GUNDUZ**
* Graduate School of Natural and Applied Sciences, Department of Industrial Engineering, Uludag University
Gorukle, Nilufer, Bursa 16059, Turkey
**Department of Industrial Engineering, Uludag University
Gorukle, Nilufer, Bursa 16059, Turkey
E-mail: tg@uludag.edu.tr

Received: 14 April 2017; Revised: 2 August 2017; Accepted: 26 October 2017

Abstract

In this study, the cognitive load that occurs in assembly works requiring human-robot collaboration is investigated. It is aimed to detect the effects of the workplaces designed with the approach of extended cognition on cognitive load and gender differences in cognitive load. Two workplace designs were used to investigate the task load that occurs in human-robot collaboration works and the effect of extended cognition on cognitive load. In both designs there was a sedentary workplace and same assembly work which requires human-robot collaboration. Differently, for the experimental group, the manual drawing was integrated to work table to detect the effect of extended cognition. For both groups task load is measured by using NASA-TLX (Task Load Index) method. Experimental results showed that the design with the extended cognition concept helps to reduce mental task load for male participants which is an important issue for yield, work safety, and quality in human-robot collaboration works. Experimental results also showed that there are no significant differences in cognitive load between genders. Unlike other studies, in this paper, human-robot cooperative works are examined according to gender difference with a point of extended cognition. The importance of the workplace design for human-robot interaction is presented.

Keywords : Cognitive ergonomics, Cognitive load, Extended mind, Extended cognition, Distributed cognition, Mental workload, Human-robot collaboration, Workplace design

1. Introduction

The use of machines, computers, tools, cars, and other mechanisms has been increasing in recent years. Therefore, the interaction between people and machines is also increasing. With this increasing interaction, the concept of cognitive load is gaining importance, especially for human-robot collaboration.

Beginning with the study of Sweller (1988) which proposed the Cognitive Load Theory (CLT), numerous studies conducted on the cognitive load are in the field of learning. According to Sweller (2011), cognitive load theory is an instructional theory based on our knowledge regarding human cognition.

CLT states that learning and problem solving in complex cognitive domains, such as computer programming, mathematics, physics and science, are typically constrained by the limited capacity of human memory and/or limited information processing capacity (Paas et al., 1994; Jalani and Sern, 2015). Thus, cognitive load is generally considered a multidimensional construct that represents the load that performing a particular task imposes on the cognitive system of a learner (Paas et al., 1994, 2010). Moreno and Park (2010) also stated that the cognitive load construct is similar to the workload construct in that it takes into consideration the demands that a certain task imposes on an individual.

This construct has casual factors (task/environment, learner and interaction between these two factors) causing cognitive load. Also, this construct has assessment factors (mental load, mental effort and performance) which reflect the measurable concepts (Paas et al., 1994). As a casual factor, learner characteristics include the expertise level, age and spatial ability, while task characteristics comprise the task format, task complexity, use of multimedia, time pressure and pacing of instruction (Paas et al., 2010).

From the assessment factors, mental load is the aspect of cognitive load that originates from the interaction between task and subject characteristics, while mental effort refers to the amount of capacity or resources that is actually allocated to accommodate the task demands. Performance is also an aspect of cognitive load and can be defined as the learner’s achievements (Paas et al., 1994, 2010).

Paper No.17-00223
[DOI: 10.1299/jamdsm.2017jamdsm0057]

Also Sweller (1988) distinguished cognitive load as two cognitive load types: intrinsic cognitive load and extraneous cognitive load. In other studies, cognitive load was classified into three categories: intrinsic cognitive load, extraneous cognitive load and germane cognitive load (Martin, 2015; de Jong, 2010; Paas et al., 2010; Jalani and Sern, 2015; Sweller, 2011). In a study by Jalani and Sern (2015), these three types of cognitive loads generate the total cognitive load. As observed in Table 1, intrinsic load emerges from a background of knowledge and expertise, and extraneous and germane loads emerge from methods and teaching design.

Table 1 Cognitive load classification according to source.

	Factors That Cause Cognitive Load	
	Expertise Level of Learner/User	Methods/Materials/Design
Cognitive Load Types	Intrinsic Cognitive Load	Extraneous Cognitive Load Germane Cognitive Load

In assembly works which human and robots perform together in the same place, analysing of the cognitive load is an important issue. While performing this type of works there are various factors that affect cognitive load. Also the cognitive load has effects on the worker's performance, yield and quality. The aim of this paper is to investigate the cognitive load in human-robot collaboration works and the effects of "extended cognition" on cognitive load. An experimental study has been conducted for this aim. A special workplace was designed for this experimental study. While workplace was designed, the casual factors of cognitive load were considered and it was ensured that to keep the extraneous cognitive load from increasing. Also, participants were chosen with the similar expertise level to not to change intrinsic cognitive load.

2. Theoretical background

In recent years, the research has concentrated on new concepts: "Extended Mind", "Extended Cognition", and "Distributed Cognition".

Clark and Chalmers (1998) asked, "Where does the mind stop and the rest of the world begin?", stating that the brain is not inside the skin and skull. In cognitive processes, external entities play an active role in which the mind becomes a coupled system. In this case, the mind is extended to external objects. They discussed this idea using the example of Otto and Inga. Otto and Inga need to memorize the address of a museum. Inga utilizes her normal biological memory, while Otto uses a notebook to copy down the address. Then, in this case, "his notebook adopts the role usually played by biological memory". In order to demonstrate the role of technology in our cognitive processes, Gallagher (2013) stated, "I cannot remember where the restaurant is, but my technology and I can". There are numerous situations in which our cognition engages with the environmental and non-neural devices. Gallagher (2013) stated that the concept of extended mind is based on the parity principle for Clark and Chalmers (1998). According to parity principle, while a task is being executed, some aspects of the environment draw attention and become part of the cognitive process.

This principle underlies the hypothesis of extended cognition (HEC). According to the HEC, the functions of the environment do not only drive attention during the task, and cognition does not simply extend from the brain; rather, the environment also shapes our cognitive process. In this case, the mind is bonded to its environment (Sprevak, 2010; Gallagher, 2013). HEC states that the mind is dependent on the environment in a causal and constitutive way. This means that environmental conditions cannot be considered only as non-mental instruments and that the environment partially forms the mechanism of the individual's mind (Sprevak, 2010).

Clark (2010) created a set of criteria for external physical processes to be part of an individual's cognitive process (Michaelian, 2012; Nakayama, 2013; Gallagher, 2013; Anderson, 2015; Greif, 2015):

1. The external resource should be "reliable, available and typically invoked".
2. The external resource should be "more or less automatically endorsed".
3. The external resource should be "easily accessible".

Shapiro (2008) indicated the aspect of social interaction of HEC, saying that "If minds extend, the boundaries that define the units of social interaction become less certain. Perhaps minds overlap. If, as some extended cognitivists believe, features of the environment comprise parts of a cognitive system, then a single piece of the world might

[DOI: 10.1299/jamdsm.2017jamdsm0057]

constitute a piece of distinct cognitive systems. More dramatically, perhaps parts of the mind of one individual may be located within the mind of another.”

Baber et al. (2014) stated that the cognition is important for the interaction of person-environment-tool-object system. The paper states that when a jeweller performs his job, he picks a tool from among his various tools, uses it and then lays it down somewhere in the workspace. Thus, while performing a task, also the workplace layout is rearranged, which is a form of distributed cognition.

In the light of this information the aim of this study is to investigate the effects of extended/distributed cognition on human cognitive load in works requiring human-robot collaboration. According to this, our hypothesis is that in the workplace that is designed according to extended cognition approach, the cognitive load on the participant should decrease. While designing a workplace, it would be better if the cognition of workers gets to extend on the workspace and the operation procedure forms.

2.1. Relationship between cognitive load and interface/workplace design

In every aspect of life, people are in contact with various machines or tools, including when teaching a lesson, working on machinery, assisting a customer, driving a car, cooking, and doing construction. A man-machine interface always exists for a given task. These tasks, interfaces and individuals always work in correlation and influence the cognitive load. Concerning this correlation and influence, usability and CLT studies have been conducted in the area of cognitive ergonomics (Ahlstrom and Freidman-Berg, 2006; Evans and Gibbons, 2007; Cierniak et al., 2008; Austin, 2009; van Gog et al., 2009a; De Koning et al., 2010; Liu and Chuang, 2010; Liu et al., 2011; Galy et al., 2012; Wang et al., 2014; van Cauwenberge et al., 2014; Huang and Chen, 2015; Jiang et al., 2015; Majooni et al., 2015; Vatavu and Mancas, 2015).

Galy et al. (2012) investigated the relationship between mental workload factors (task difficulty, time pressure and alertness) and cognitive load types. They stated that the task difficulty causes intrinsic cognitive load, time pressure causes extraneous cognitive load, and with alertness they all cause germane cognitive load. It can be said that to reduce the total cognitive load on a worker we can only reduce extraneous and germane cognitive load. To manage this, while the workplace design is being considered, time pressure and alertness factors must be searched. Also, these factors should be limited due to causing extraneous load.

In the area of human-computer interfaces, the interface design is an important issue. Several studies have been conducted concerning this topic (Evans and Gibbons, 2007; Liu and Chuang, 2010; Majooni et al., 2014).

Various studies have been conducted on interface design, which investigate the effects of text, pictures, animations, voices, etc., and their combinations on individuals (Austin, 2009; Liu and Chuang, 2010; Liu et al., 2011; Majooni et al., 2014). Thus, the effects of interface design on human are investigated. Liu and Chuang (2010) and Liu et al. (2011), showed the negative effects of redundant images and information. On the other hand, Majooni et al. (2015) revealed with their experiment that when picture is presented before the text, it causes less cognitive load than the load in reverse sequence. One major point of the interface design is the interactivity of the interfaces, especially those for computer-based learning systems. Evans and Gibbons (2007) examined whether interactivity reduces the effectiveness of learning by using two types of multimedia (systems with interactive elements and without interactive elements). Van Gog et al. (2009a) and De Koning et al. (2010) investigated the attention guidance’s effect on cognitive load. For this, De Koning et al. (2010) prepared three different interfaces (no-cueing condition, single-cueing condition, multiple-cueing condition) for the educational content; while Van Gog et al. (2009a) performed their experiments with or without attention guidance. If the attention guidance is adapted to assembly workplaces, it can cause to extend the cognition of worker to workspace.

Jiang et al. (2015) investigated the difficulty level of a task’s effect on cognitive load. They set three difficulty levels for the task (in which a continuously moving surgical tool pointed to circles).

Some researchers investigate the correlation between tasks and interfaces (Ahlstrom and Freidman-Berg, 2006; Wästlund et al., 2008; Cierniak et al., 2009; Van Gog et al., 2009a; Wang et al., 2014; Van Cauwenberge et al., 2014, Vatavu and Mancas, 2015). Ahlstrom and Freidman-Berg (2006), Van Cauwenberge et al. (2014) and Vatavu and Mancas (2015) also investigated the effects of second screen viewing in their researches.

Some researchers have investigated the correlation between individuals and interfaces (Chevalier and Kicka, 2006; Huang and Chen, 2015; Baber et al., 2015).

Instructional design, element interactivity, etc., can be effective on intrinsic or extraneous cognitive load levels in different ways. These effects can be observed in the studies of Sweller, 2011; Sweller et al., 2011.

Through these effects; *variability* and *isolated elements* are the components that can change the level of intrinsic cognitive load. Other effects (*goal-free, worked-example, split-attention, modality, redundancy, element interactivity, expertise reversal, problem completion, guidance fading, imagination* and *transient information*) are the effects that can change the extraneous cognitive load (Sweller, 2011). While Liu and Chuang (2010) and Liu et al. (2011) investigated the effect of redundancy, Austin (2009) investigated the effects of modality, redundancy and split-attention. Also Austin (2009) found out that the split attention effect on learners increased the extrinsic cognitive load.

According to these studies, it was considered that not to impose extra mental load arising from extraneous load while designing workplace for the experimental study of this paper.

2.2. Cognitive load measurements

Researchers have sought methods that would optimize the cognitive load.

Martin (2015) classified the methods for measuring the cognitive loads according to their relationships and data types. There are two categories of data types: subjective and objective measurements. There are also two categories of relationship types: direct and indirect measurements. Eye-tracking and dual-task methods are referred to as direct measurements. With these types of methods, data can be collected in real time or use the same working memory with the task. Miller (2001) divided the subjective methods into two categories: unidimensional and multidimensional. Cognitive load measurement methods that obtained from these two studies (Miller, 2001; Martin, 2015) are presented in Table 2.

Table 2 Cognitive Load Measurement Methods

Data Type	Relationship Type	Cognitive Load Measurement Methods
Subjective		Unidimensional Scales Multidimensional Scales
Objective	Direct	Eye-tracking Dual-task methods Brain activity measures (e.g., MRI, fNIRS)
	Indirect	Learning outcomes Time on task Help-seeking behaviour Physiological approaches using EEG or cardiovascular metrics Efficiency measures

Subjective methods are based on self-reported techniques (Chevalier and Kicka, 2006; Cierniak et al., 2008; van Cauwenberge et al., 2014). Self-reports of stress and mental effort that use Likert-type scales are subjective methods (Sweller, 2011; Martin, 2015). The NASA Task Load Index Scale (NASA TLX) and Rating Scale Mental Effort (RSME) methods have been used in the studies conducted by Seckiner and Toraman (2015) and Matthews et al. (2015).

Unidimensional rating scales are easier to use but can only measure workload based on one dimension. The multidimensional rating scales are more complex methods, but unidimensional rating scales are more sensitive (Miller, 2001).

According to Martin (2015), although subjective methods are not able to provide an absolute scale for ratings of cognitive load, they can be useful for repeated comparisons of load with the same group of learners.

According to Van Gog et al. (2009b), concurrent and retrospective verbal report techniques are the most commonly used techniques.

In this study, NASA RTLX (NASA Raw Task Load Index) method was chosen. Because this method does not cause an interruption on the main work. In this method, the work load is measured in six dimensions (mental demand, physical demand, temporal demand, performance, effort and frustration). According to Delice (2016) this method is a non-weighted version of NASA TLX and most frequently used method to investigate the dimensions separately. Since it is needed to investigate these dimensions separately for the experimental work, this method was chosen.

[DOI: 10.1299/jamdsm.2017jamdsm0057]

3. Materials and methods

40 participants (22 male, age *M*=28.9, *SD*=7.7; 18 female, age *M*=24.4, *SD*=4.6) participate in the experiment. 2 × 2 factorial design was used with factors Gender (Male vs. Female) and Workplace Design (without extended cognition approach and with extended cognition approach), resulting four conditions (Table 3).

Table 3 The conditions of 2×2 factorial design

Groups	Gender	Extended Cognition Approach	*n*
Group 1	Male	w/o EC	11
Group 2	Male	w/ EC	11
Group 3	Female	w/o EC	9
Group 4	Female	w/ EC	9

Participants were divided into two groups according to their gender. Then both groups were randomly divided into two groups.

To investigate the effects of extended cognition, two workplace designs were used. The control group worked in a standard workplace while the experimental group worked on the work table prepared by the approach of extended/distributed cognition.

Before the experiment, all the participants were informed about the task by giving an operating instruction form (paper) and also, informed about the velocity of the robot arm and the component order. After that the operating instruction form was put in its place near the robot arm.

The standard workplace is shown in the Fig. 1. The workplace was designed as a sedentary workplace and it was about 4 m^2. Degree of freedom of the robot that participants worked in collaboration with was six. On the left side of the work table, the work components were placed and on the right side there was the green platform. These work parts should be placed on that green platform by the participants. Participants were asked to prepare the task presented in Fig. 2, with the little components which were brought by a robot arm in constant velocity and a predetermined order. There were 12 components in size of 4×2 unit and 1 component in size of 2×2. Also, the components were different in terms of their colours. For first layer, there were 7 blue components (1 2×2 and 6 4×2), for second layer, there were 5 red components and for third layer, there was 1 yellow component. The sequence of the components was blue, red and yellow (Robot arm started with the component in size of 2×2).

To investigate the effects of the extended cognition, the standard workplace was rearranged as secondary workplace. Although the whole procedure was the same with the work of control group, experimental group was given the manual drawing (Fig. 2) on their black work table above the green platform, additionally. The manual drawing paper was placed on their black work table according to set of criteria of Clark (2010), so they could easily reach. Thus, the participants would be extended their cognition to the workplace with this rearrangement.

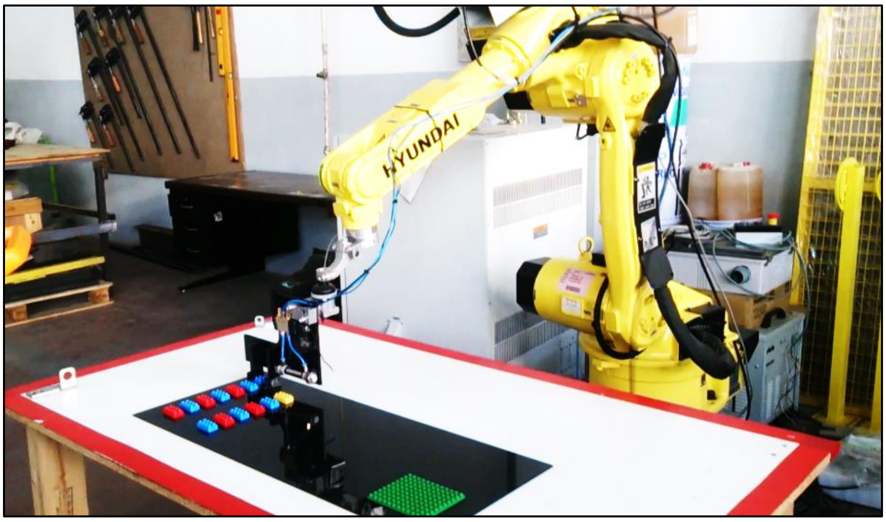

Fig. 1 Robot arm and workplace.

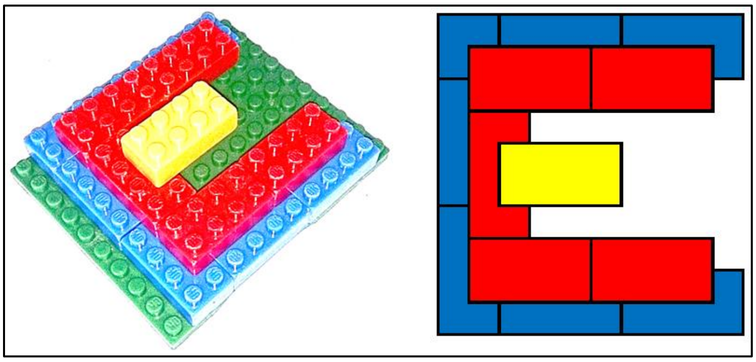

Fig. 2 Manual drawing.

There was no time limitation for both groups. The completion time (to complete simultaneously with the movements of robot arm or vice versa) depended on decision of participants. Participants did not have to finish the work by the end of the motion of the robot arm. They could continue to assemble the components until they completed or gave up. In this way, an extra time pressure was avoided. Because as mentioned above time pressure causes extraneous cognitive load.

After the experiment, self-report method was used to measure the cognitive load on participants. Participants were asked to rate their workload on the NASA RTLX form and also asked to indicate their age and education. Both male and female participants passed through the same stages.

We hypothesized that values should be similar for each group for performance, physical demand, effort and frustration dimensions because the task is easy to success and there are no differences between tasks physically. However, we also hypothesized that for mental demand and temporal demand experimental groups should be exposed to lower cognitive load. Due to the structure of the task, there would not be differences between groups for the dimensions which include physical factors while there should be differences for dimensions which include mental or cognitive factors. Also we hypothesized that there should be no differences for different genders.

4. Results and discussion

Independent samples *t* test was performed to analyse the datum derived from NASA RTLX. Statistical results are shown in Table 4 and 5.

Table 4 Statistical results of NASA RTLX ratings for gender differences.

NASA TLX Dimensions	Groups	*Mean*	*SD*	*p*-Value
Mental demand	Male	8,045	5,028	0,817
	Female	8,389	4,132	
Physical demand	Male	3,591	3,187	0,392
	Female	2,833	2,093	
Temporal demand	Male	7,591	4,876	0,867
	Female	7,333	4,690	
Performance	Male	8,273	7,159	0,998
	Female	8,278	4,099	
Effort	Male	7,636	5,076	0,470
	Female	6,556	4,090	
Frustration	Male	6,545	4,828	0,725
	Female	7,111	5,246	

The results showed us that for gender differences as expected there were no significant differences between groups and for each dimension (Table 4). According to this findings for the works do not require physical strength, there is no obstacle to increase the number of female workers. Thus, the promotion of female employment should be supported.

Table 5 Statistical results of NASA RTLX ratings for extended cognition approach.

NASA TLX Dimensions	Groups	*Mean*	*SD*	*p*-Value
Mental demand	w/o EC w/ EC	9,65 6,75	4,85 3,92	0,044
Physical demand	w/o EC w/ EC	2,95 3,55	2,26 3,19	0,496
Temporal demand	w/o EC w/ EC	9,05 5,90	5,28 3,60	0,033
Performance	w/o EC w/ EC	8,00 8,55	6,44 5,48	0,773
Effort	w/o EC w/ EC	8,40 5,90	5,36 3,46	0,088
Frustration	w/o EC w/ EC	8,10 5,50	5,59 3,97	0,098

Also, for extended cognition approach statistical results (Table 5) showed us that for mental demand and temporal demand; (for mental demand t=0.044; for temporal demand t= 0.033) our hypotheses were confirmed in which we expected the approach of extended/distributed cognition to decrease mental demand, temporal demand. Because these dimensions are directly related with cognitive load. Thus, the importance of the designing workplaces with the extended cognition approach was raised. Extending the cognition of workers to the workplace reduce the cognitive load. As we expected, there were not any significant differences in physical demand, performance, effort and frustration dimensions (for physical demand, t=0.496; for performance, t=0.773; for effort, t=0.088; for frustration, t=0.098). There was not any significant effect of extended/distributed cognition approach between the control group and the experimental group for the physical demand, performance, effort and frustration dimensions (Table 5). As we expected, because the tasks (both for the control group and the experimental group) did not require high physical effort; physical demands, efforts and frustrations of the groups were similar. Furthermore, since the task was a simple assembly work, all of the participants completed the task without discrimination between the groups. Because of that, as expected, there was no significant difference in performance values. In brief, we did not expect any differences between the groups in the dimensions which include physical impression.

The results can be seen in box plot graphs for each dimension of Nasa TLX in Fig. 3. For mental demand and temporal demand dimensions, the similar tendency can be seen. Besides for the workplace with extended cognition approach, the medians of ratings are lower than the standard workplace. Although there was no significant difference between genders, for the male participants the gap was bigger dependent on extended cognition approach. When the workplace designs with extended cognition, females experienced more mental and temporal demands than the males. In the standard workplace, females experienced less mental and temporal demands than males. The reason of this difference may occur from the differences between the number of participants. In the future studies with more participants, this situation can be changed. For physical demand dimension, the ranges of the four groups were similar and narrow. It is an expected result due to the nature of the task. Similarly, for performance dimension, the ranges of the four groups were similar but distinctly, for this dimension the ratings were higher. This is also because of the nature of the task. Because task was not difficult to complete. Lastly, for the frustration dimension, there was no significant differences between standard workplace and experimental workplace independent from gender. However, the ranges of both female and male participants who worked in standard workplace are wider than the other groups. Also, for this dimension, the graph has a similar tendency with mental and temporal demands.

[DOI: 10.1299/jamdsm.2017jamdsm0057]

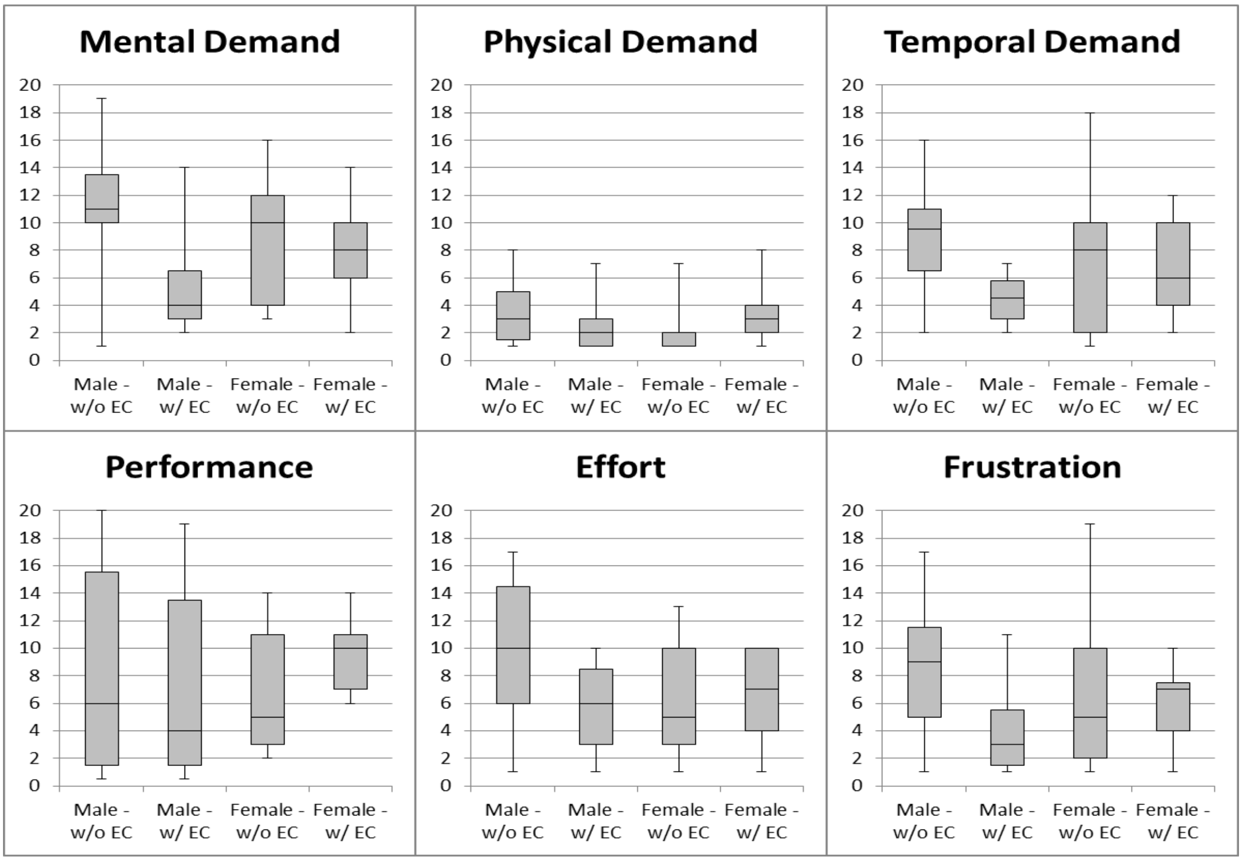

Fig. 3 Box plot graphs for each dimension of Nasa-TLX.

In this paper, we reported on cognitive load, its effects and types, and extended cognition. Although there are various experimental studies measuring cognitive load, those papers do not include the issues concerning extended cognition. However, the effects of extended cognition on cognitive load should not be ignored by researchers. It should affect the cognitive load directly because the existence of extended cognition appears and influences the workload when using tools, interfaces or various area of life. As Ahlstrom et al. (2006) stated, the workplace design has impact on controller's efficiency.

In their studies, Van Gog et al. (2009a) and De Koning et al. (2010) investigated the effects of attention guidance on cognitive load. Similarly, Jamet (2014) investigated the effects of cueing. Although Van Gog et al. (2009a) and De Koning et al. (2010) could not find the evidence of attention guidance's effects on cognitive load, Jamet (2014), for their diagram completion task, found out that the cueing group performed significantly better than the no-cueing group. When similar implementations are wanted to use in an assembly workplace, they cause the workers' cognitions extend over the workplace.

In addition, initial studies mostly examined the cognitive load, but recent researches have extended their focus to the interaction of mind and its environment, extended cognition and distributed cognition. Extended/distributed cognition is a new topic for industrial use in human-robot collaboration.

In our task, we used extended/distributed cognition approach for an assembly work, and as a result, our findings showed that cognitive load on the worker could decrease by designing workplace with the approach of extended/distributed cognition. Also the results showed that the task load does not change between females and males. It can help to increase the numbers of female workers in this kind of assembly works with collaboration with robots.

5. Conclusion

In this paper, we studied the relationship between cognitive load, extended cognition and cognitive ergonomics to shed light on future works. We perform an experiment about the effects of workplace design with extended/distributed cognition approach on the cognitive load of people while doing assemble work with small components in collaboration with a robot.

[DOI: 10.1299/jamdsm.2017jamdsm0057]

While designing a workplace, considering cognitive load is as important as considering physical workload in human robot cooperation works. Our findings showed us that designing workplaces with the approach of extended cognition could reduce cognitive load on workers.

As it was presented, both the types and the effects of cognitive load are relevant and affected by one another. Additionally, these factors have an effect on workload. According to this, in order to optimize the cognitive workload, we should not only try to reduce the total cognitive load but also optimize it by considering the types and effects of the cognitive load.

Furthermore, a relatively new issue is becoming increasingly prominent, which is that the extended mind (or extended cognition/distributed cognition) and its relationship with cognitive load cannot be denied.

From our point of view, while designing a product, a workplace, a work method or an interface, etc., the factors concerning cognitive load should be considered. It is important that the designs should be appropriate according to the cognitive load types and effects and extended cognition issues.

In this way, for workplace design, the errors caused by users decrease and the standardization for processes increases. Thus, the quality defects also decrease. Because of this decrease, the yield will increase. For product design, the yield will increase by increasing the usability and customer satisfaction.

Further studies should include how the extended cognition may affect the cognitive load of the users depending on the change in velocity. In future works it could be investigate the effects of velocity and the appropriate velocity for eye-hand-brain coordination. Also, for the future studies, effects of the relation between genders and velocity together on cognitive load could be investigated.

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[DOI: 10.1299/jamdsm.2017jamdsm0057]

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[DOI: 10.1299/jamdsm.2017jamdsm0057]