A Review of Respiratory-Based Measurement Methods for Assessing the Cognitive Workload

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Abstract

One of the objective measuresof mental workload is through respiratory method. Respiration is a physiological process mainly related to the exchange of O2 and CO2 from body tissues to the air. The aim of this study is to review respiratory method and mental workload research for developing cognitive workload measurement methods based on a literature study. As acknowledge by authors, there are 28 studies using respiratory approach, with 13 parameters in which the respiratory rate parameter is often used. There are 7 domains and 1 nonspecific domain about the studies. From the literature review, considering its advantages, the respiratory seems to be a promising approach in the study of cognitive workload measurement in particular in Indonesia due to its low cost and practical reasons.

1. Introduction

Recently, the characteristics of work in industry and daily activities has shifted from physical activity to mental activities. This change is triggered with the development of industry 4.0, which is characterized by the massive use of internet and cloud system. In addition, the changes also involve cognitive abilities (for example thinking, remembering, and making decisions) in a large extent. The need of cognitive abilities to fulfil the job demand in recent activities raises the issue of cognitive load. The cognitive workload, which is defined as the difference between work demand and worker' cognitive capacity, (Gopher and Donchin 1986) has become an important issue in recent years, in relation to the efforts to improve the performance of the systems. The term cognitive workload sometimes interchange with the term of mental workload in some studies. Maintaining the optimal cognitive workload will ensure the optimal performance. Too low of cognitive workload (i.e., under load) will cause boredom and decreased performance (for example, increasing vigilance decrement). In contrast too high of cognitive worklaod (i.e., overload) will causes errors as well as work accidents. Therefore, measuring cognitive workload is very important.

Measuring cognitive workload should fulfill some criteria. According to O'Donnel and Eggemeier (1986) cognitive workload measures should sensitive (i.e., can differentiate the level of cognitive workload on the same job), acceptable (i.e., accept by the respondents), diagnosticity (i.e., can distinguish sources of cognitive workload variation and the contribution of each source the total cognitive workload), not intrusive (i.e., does not interfere with the work or activity to be measured or the workload to be measured), , and minimal equipment (i.e., using minimum equipment so that the measuredoes not affect the performance of the respondent).

Measuring workload can be done subjectively that is through the assessment of employee questionnaires that are measured at the end of the activity, for example Rating Mental Effort Scale (RSME, Zijlstra and Van Doorn 1985, Widyanti et al. 2013), Subjective Workload Assessment Technique or SWAT (Reid and Nygren 1988), and NASA Task Load Index or NASA-TLX (Hart and Staveland 1988). It can be done objectively as well, using a physiology approach such as using heart rate variability or HRV (Widyanti et al. 2013), Galvanic Skin Response or GSR (Widyanti et al. 2017) and electroencephalograph or EEG (Rahma et al. 2020). Both subjective and objective method have their own advantages and disadvantages.

Respiratory based measures is a promising objective measure of cognitive workload due to several reasons. The aim of this study is to provide a literature review about respiratory and mental workload research.

2. Literature Review

The review is conducted through search engines of Google Schoolar with keywords of combination of 'respiratory' and 'mental workload'. Reference selection must include the following criteria:

- Only literatures from year of 1990 until now.
- Only literatures with rank quartile 1 until 3 based on scimago journal rank.
- Only literatures that using experimental design.

3. Results

The most used objective measures of mental workload is HRV measure, which correlates with respiratory indicators. According to Wilson (1993) there are two variability bands that gets the greatest interest: 0.06-0.10 Hz related to blood pressure regulation and 0.12-0.40 Hz related to respiratory influences on the cardiac rhythm. According to Charles and Nixon (2019), respiration is ranked second after HRV as a method used in measuring cognitive load in several studies.

According to Roscoe (1992) respiration is defined as a physiological process related to the exchange of O2 and CO2 from the body to the air, and vice versa. Inspiration is the process of inputting the O2 in cell activity form the air, whereas expiration is the process of exhaling the CO2 to the air. The demand of O2 is determined by the level of activity or metabolism, not only physically but also psychologically, showing behavioural processes (Wientjes et al 1998). A number of indicators used in the respiratory approach are as follows:

3.1 Respiratory rate (RR)

Respiratory Rate (RR) is defined as the amount of breath taken per minute. RR parameters have been widely used as indicators of emotional state, stress, arousal, and mental workload (Roscoe 1992). The measurement units of RR are cycles per minute (Veltman 2002) or breaths per minute (Veltman 2002, Roscoe 1992). Healthy people at rest have a RR of around 12 to 20 breaths/min (Roscoe 1992). Variations in RR can result from changes in inspiration duration (Ti) or expiration (Te) (Wientjes et al 1998).

3.2 Respiratory amplitude

Respiration amplitude is defined as the amount of air absorbed during the breathing cycle. The respiratory amplitude is related to the tidal volume (TV), the volume of gas in (Vi) and volume of gas out (Ve) the respiratory system for each breath (Abbasi et al. 2004).

3.3 Minute ventilation (MV)

Minute ventilation (MV) can be defined as the amount of air inhaled in one minute and therefore depends on the RR and TV (Grassmann 2016). MV also refers to the total volume of gas that expires for 1 minute (Abbasi et al. 2004). MV increases with an increase in tidal volume and respiratory rate.

3.4 I:E ratio (Ti/Te)

Ratio of inspiration and expiration refers to the ratio of inspiration (Ti) and expiration (Te) (Beda et al. 2007). Ti is the duration of gas entering the respiratory tract and Te is the duration of gas leaving the respiratory tract. In normal spontaneous breathing, the expiration time is about two times longer than the inspiration time.

3.5 Mean inspiratory flow rate (TV/Ti)

Mean inspiratory flow rate (TV/Ti) refers to an index of the central inspiratory drive mechanism intensity (Gautier 1980). The parameter TV/Ti shows the rate of lungs filling with air, and is often defined to as inspiratory flow rate (Wientjes 1998). Based on Wientjes et al. (1998), the unit of TV/Ti is ml per second.

3.6 Inspiratory duty cycle (Ti/Ttot)

The inspirational duty cycle shows the fraction of an active and energetic periodic cycle (Boiten 1994). Based on Wientjes et al. (2016), Ttot defines as the breathing cycle total duration that includes Ti and Te. Ti/Ttot shows the active breathing cycle fraction. The duty cycle can be increased by prolongation of Ti, faster lung emptying (ie shortening of Te), and / or the subsequent inspiration *beginning.*

3.7 Proportion of ribcage breathing to TV (% RCi)
%RCi refers to a unit that represents the rib cage excursions percent contribution to the tidal volume (Cancelliero-Gaiad 2014). The %RCi contribution to TV ratio is got by dividing the inspired volume in the RC band with the inspired volume in the rib cage algebraic sum (RC) and abdominal signal (AB) at the point of inspiratory tidal volume peak.

3.8 Partial pressure of end-tidal carbon dioxide (petCO2)
petCO2 is defined as an estimate of arterial pCO2. The partial pressure of carbon dioxide (pCO2) is the measure of carbon dioxide within venous or arterial blood. petCO2 can be considered as breathing indicator according to metabolic needs (Grassmann et al 2015). The unit is mmHg (Grassmann et al. 2017).

3.9 Respiratory Gas Analysis
Respiratory Gas Analysis is the study of gas mixtures that are inspired or expired by humans (Roscoe 1992). The unit is in ml/min (Backs and Seljos 1994).

3.10 Respiratory Exchange Ratio (RER)
RER has been studied to determine energy expenditure in demanding situations (Troubat et al. 2008). RER is the ratio between the amount of CO2 produced in metabolism and O2 used.

3.11 Respiration modulation depth (MD)
The depth of modulation is the average difference between peaks and through (Hogervorst 2014). The depth of MD is characterized by a significantly greater amplitude at a lower respiratory rate (Zheng et al. 2014).

Table 1 below shows research that uses a respiratory approach in measuring cognitive workload. The 28 studies are using respiratory approach, with parameters such as, RR, TV, respiratory gas analysis, minutes ventilation, expiratory volume, inspiratory time, mean inspiratory flow rate, inspiratory duty cycle, ratio I/E, %RCI, petCO2, RER, and respiration modulation depth. Table 2 shows the domains of research on respiratory measurement. There are 7 domains and 1 nonspecific domain. Table 3 shows the relation between respiratory parameter and measures of cognitive load.

The indicators used in the respiratory approach generally reflects cognitive processing and distinct parameters differ in sensitivity. While higher demand are clearly marked by faster respiratory rate and higher minute ventilation, the breathing amplitude seems to remain stable also the mean inspiratory flow rate (Wientjes et al. 1998) and %RCi (Vlemincx 2010) seems to increase. Besides that, CO2 release and petCO2 significantly decreased, whereas oxygen consumption stayed stable (Grassmann et al. 2017; Troubat et al. 2008)

4. Discussion
Mental workload measurement with objective approach is a measurement that uses the body's physiology approach. The advantages of this approach is non-instructive and providing fast response to the shifts in mental workload. Several approaches are used in mental workload measures, such as heart rate variability, electroenchephalography, galvanic skin response, eye tracker, and respiratory.

Table 1. Researchs used a respiratory approach in measuring mental workload.

Author (Year)	Parameter(s)												
	RR	TV	VO_2, VCO_2	MV	V_e	T_i	TV/ T_i	T_i/T_e	T_i/T_{tot}	%RCi	$petCO_2$	RER	MD
Roscoe (1992)	v	v	v										
Wilson (1993)	v	v											
Backs and Seljos (1994)	v	v	v										
Brookings et al. (1996)	v	v											
Veltman and Gailllard (1998)	v	v				v							
Wientjes et al. (1998)	v	v		v			V		v		v		
Fournier et al. (1999)	v	v											
Bernadi et al. (2000)	v			v									
Houtven et al. (2002)	v										v		
Veltman (2002)	v	v											
Fairclough et al. (2005)	v												
Beda et al. (2007)	v	v						v					
Schleifer et al. (2008)	v										v		
Troubat et al. (2008)	v	v	v									v	
Mehler et al. (2009)	v												
Pattyn et al. (2010)	v	v							v				
Karavidas et al. (2010)	v	v		v									
Vlemincx et al. (2010)	v	v		v						v			
Hogervorst et al. (2014)	v												v
Kodesh and Kizony (2014)	v	v			v								
Grassmann et al. (2015)	v										v		
Kuehl et al. (2015)	v												
Nagasawa and Hagiwara (2016)	v												
Wang et al. (2016)	v	v											
Grassman et al. (2017)	v										v		
Malagoli et al. (2017)	v	v											
Bruna et al. (2018)	v	v											
Bruder et al. (2019)	v												

Table 2. The domain of research on respiratory measurement of mental workload.

Domain	Reference	Number
Simulated aviation operations	Roscoe 1992; Fournier et al. 1999; Veltman and Gailllard 1996; Veltman and Gailllard 1998; Wang et al. 2015; Fairclough et al. 2008; Bruna et al. 2018; Karavidas et al. 2010	7
Aviation operations	Grassman et al. 2015; Grassmann et al. 2017; Pattyn et al. 2010	3
Simulated and real aviation operations	Veltman 2002; Wilson 1993	2
Air traffic management	Brookings et al. 2019	1
Automotive	Mehler et al. 2009	1
Maritime	Malagoli et al 2017	1
Office	Schleifer et al 2008	1
Non spesific domain	Backs and Seljos 2002; Wientjes et al. 1998; Bernadi et al. 2000; Houtven et al. 2002; Beda et al. 2007; Troubat et al. 2008; Vlemincx et al. 2010; Hogervorst et al. 2014; Kodesh and Kizony 2014; Kuehl et al. 2015; Nagasawa and Hagiwara 2016; Bruder et al. 2019	12

Table 3. The relation of respiratory physiological measures and cognitive workload.

Measure	Workload	References
RR	+	Wilson 1993; Grassmann et al. 2016; Backs and Seljos 1994; Brookings et al. 1996; Fournier et al. 1999; Fairclough et al. 2005; Mehler et al. 2009
TV	+	Wilson 1993; Veltman and Gaillard 1998; Veltman 2002; Backs and Seljos 1994
VO2, VCO2	+/-	Backs and Seljos 1994 / Troubat et al. 2008
MV	+	Wientjes et al. 1998; Vlemincx et al. 2010; Karavidas et al. 2010
Ve	+	Kodesh and Kizony 2016
Ti	+	Veltman and Gaillard 1998
TV/ Ti	+	Wientjes et al. 1998
Ti/Te	-	Beda et al. 2007
Ti/Ttot	+	Wientjes et al. 1998; Patty et al. 2010
%Rci	+	Vlemincx et al. 2010
petCO2	-	Grassmann et al. 2015
RER	+	Troubat et al. 2008
MD	+	Hogervosrt et al. 2014

Respiratory is a physiological process mainly related to the exchange of O2 and CO2 from body tissues to the air. Respiration is measured using two elastic belts which placed around the chest and abdomen. There are 13 paramaters that usually used in respiratory studies, such as RR, TV, respiratory gas analysis, minutes ventilation, expiratory volume, inspiratory time, TV/Ti, TV/Ttot, ratio I/E, proportion of ribcage breathing to Vi, petCO2, RER, and respiration modulation depth.

In Indonesia, the research of cognitive workload measurement was done in several studies. There are several research in Indonesia that measured WML using several approach, such as heart rate variability/HRV (Widyanti et al. 2013), sweat glands/Galvanic Skin Response / GSR (Widyanti et al. 2017), eye blink (Widyanti et al. 2017), and electroenchepalograph/EEG (Rahma et al. 2020). Thus, the respiratory approach is relatively new in the study of cognitive measurement in Indonesia.

The RR parameters of respiratory are often used. Brookings et al. (1996) state that the increased respiration rate may have been a direct effect of the increase of metabolic demands required to perform the task. Furthermore, the RR is the most useful of the respiratory measures for MWL measurement (Roscoe 1992). RR was found to be the most sensitive measure in the present study, which increases significantly with the additional cognitive load under all conditions tested.

Considering the high need to measure cognitive load in both laboratory and industrial settings, as well as the practical advantages of respiratory measures, this measures seems promising in measuring and optimizing cognitive load in Indonesia.

5. Conclusion

RR and TV are indicators of respiratory approach that is often used. The respiratory approach is relatively new in the study of cognitive measurement in Indonesia.

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