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Analysis of Mental Workload in Appropriate Technology (AT) for Agricultural Machinery Using Heart Rate Variability (HRV) Parameters

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Abstract

Appropriate Technology (AT) is designed to substitute manual work and to increase productivity for small-medium businesses. Due to its low-cost technology that affects its design quality, the acceptance of AT appears to be low. A guideline has yet to be available to determine AT's design quality. The purpose of this study was to explore the efficacy of physiological measures collected from a Heart Rate Monitor (HRM) in differentiating mental workload in using AT. If applicable, these measures can provide objective data for AT evaluation. Several parameters were collected from HRM, including frequency domain and time domain. Two ATs were used for evaluation that represented "good" and "poor" agricultural processing machines. Eleven participants were involved in this study in which they used both ATs. The result of this studyis the ratio of Low Frequency and High Frequency (LF/HF) parameter detects differences perceived by the participants. The increase in the LF/HF value from the Commercial Extruder to the Customized Extruder is directly proportional to the increase in mental workload, where the Commercial Extruder is defined as a "good" AT design, and the Customized Extruder as a "poor" AT design. Therefore, it can be concluded that designs with specific guidelines can reduce the mental workload perceived by operators.

Keywords*: Agricultural, Appropriate Technology (AT), Design Quality, Heart Rate Monitor, Mental Workload*

Abstrak

Teknologi Tepat Guna (TTG) dirancang untuk dapat menggantikan pekerjaan manual dan meningkatkan produktivitas dari usaha kecil menengah. Akan tetapi, teknologi yang berkembang karena keterbatasan biaya berdampak pada kualitas desain dan penerimaannya yang cenderung rendah. Belum ada panduan desain yang dapat digunakan untuk menentukan kualitas dari desain TTG. Tujuan dari penelitian ini adalah untuk mengeksplorasi efektivitas alat ukur fisiologis yang memanfaatkan pemantauan pada detak jantung untuk dapat mendeteksi beban kerja mental ketika mengoperasikan TTG. Kedepannya, hasil penelitian ini dapat memberikan data objektif dalam mengevaluasi TTG. Beberapa parameter didapatkan dari pemantauan detak jantung, baik pada domain waktu maupun pada domain frekuensi. Dua mesin TTG digunakan pada penelitian yang merepresentasikan mesin agrikultural yang "telah mendekati kriteria ergonomis" dan "belum memenuhi kriteria ergonomis". Sebelas partisipan terlibat dalam penelitian ini dimana mereka mengoperasikan kedua mesin. Hasil dari penelitian ini yaitu parameter rasio antara frekuensi rendan frekuensi tinggi (LF/HF) sensitif dalam mendeteksi perbedaan yang dirasakan oleh partisipan. Terdapat hubungan langsung antara peningkatan nilai LF/HF ketika beralih dari ekstruder komersial ke ekstruder yang disesuaikan dengan peningkatan beban kerja mental. Dalam konteks ini, ekstruder komersial dianggap sebagai TTG yang dirancang "mendekati kriteria ergonomis", sedangkan ekstruder yang disesuaikan dianggap sebagai TTG yang "belum memenuhi kriteria ergonomis". Oleh karena itu, dapat disimpulkan bahwa desain yang mengikuti panduan-panduan tertentu dapat secara efektif mengurangi beban kerja mental yang dirasakan oleh operator.

Kata kunci: Agrikultural, Beban Kerja Mental, Kualitas Desain, Pemantau Detak Jantung Teknologi Tepat Guna (TTG)

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Intoduction

Small and Medium Enterprises (SMEs) play a crucial role in the Indonesian economy, with significant contributions to the Gross Domestic Product (GDP). In 2020, SMEs contributed approximately 8,500 trillion rupiahs, accounting for around 61.97% of the total national GDP. This significant contribution is strongly linked to the job opportunities created by Small and Medium Enterprises (SMEs), as they employ 97% of the workforce within the business sector (Kementrian Investasi/BKPM, 2023). Several factors contribute to the remarkable influence of SMEs on the economy (Tambunan, 2012): (1) SMEs produce affordable goods, (2) SMEs have a labor-intensive nature, (3) Many SMEs operate within the agricultural sector, (4) SMEs demonstrate resilience during economic crises, and (5) SMEs are distributed across both rural and urban areas.

Appropriate technology (AT) has emerged as a machine that is further developed due to its ability to replace manual labor at a low cost (Sianipar et al., 2013). According to Venkatesh & Davis (2000), many technologies are not effectively utilized alongside the remarkable emergence of new technologies, including AT. In the case of AT, several factors contribute to its underutilization. These factors primarily stem from the developers' primary focus on economic, technological (Rahayuningtyas & Afifah, 2016), and technical aspects (Moses et al., 2019). Additionally, the need for design guidelines prioritizing creating user-centric and high-quality AT machines hinders their effective utilization (Taofik & Mauluddin, 2015).

Considering that AT originates from the community's desire to finish their tasks, which typically involve physical tasks, AT is designed to reduce the intensity of physical labor and leverage cognitive abilities (Ghanavati et al., 2019). This leads to a decrease in physical workload and an increase in mental workload. An excessive mental workload can lead to temporary fatigue and have a negative impact on performance, resulting in errors and reduced decision-making abilities. On the other hand, an excessively low mental workload can lead to boredom and represent an inefficient use of human resources. Hence, assessing the mental workload in human-machine interactions is essential to ensure optimal performance (Qu et al., 2021). Generally, a well-designed machine positively impacts reducing the mental workload experienced by its users (Parasuraman & Mouloua, 2018).

Three parameters are used to measure mental workload: task performance measurement, subjective measurement, and physiological measurement (Young et al., 2015). The physiological measurements help the system designer to accurately and quickly evaluate by providing real-time and unbiased data (Tran et al., 2007). Numerous studies have provided evidence of a correlation between mental workload and physiological responses in various types of activities such as pilot simulation (Causse et al., 2015), the control room of nuclear power plant (Choi et al., 2018), driving with automated systems (Radhakrishnan et al., 2023), driving simulation (Collet et al., 2014), and computer task (Stasi et al., 2013). Nevertheless, it is important to recognize that, as Charles & Nixon (2019) stated, there is no universally used measure of mental workload. This is primarily because physiological responses to mental workload highly depend on the specific task scenarios being performed.

Heart rate or heart rate variability stands as the prevailing physiological measurement for assessing mental workload across a variety of research investigations (Tao et al., 2019). This measurement is popular due to its non-intrusive nature, as it does not disrupt participants' activities or cause any harm or injury (Paso et al., 2013). HRV (Heart Rate Variability) has two measurement domains: frequency domain and time domain. Among the numerous parameters in the frequency domain, the LF/HF ratio is the most commonly used, followed by high-frequency (HF) and low-frequency (LF) components. In the time domain, IBI (Interbeat Interval) is the most frequently used parameter, followed by the ratio of the NN50 to the number of RR intervals (pNN50), the standard deviation of RR intervals (SDNN), and the root mean square of the difference between adjacent RR interval (RMSSD). All parameters in frequency and time domains havebeen demonstrated to exhibit sensitivity to mental workload (Tao et al., 2019).

The research conducted by (Maulid et al.,2019), (Siswandi & Nugroho, 2020), and (Irawan & Sahal, 2022) represents some of the recent studies examining mental workload on AT operators. Based on the findings, the majority of research on mental workload measurement in AT operators typically utilizes subjective assessments, often employing the National Aeronautics and Space Administration Task Load Index (NASA-TLX) questionnaire, Focus Group Discussion (FGD), or interview. Subjective measurements are highly dependent on respondents' perceptions. Despite the numerous studies on mental workload in various activities, there are currently need for more research specifically addressing the mental workload arising from the use of AT with physiological measurements. Furthermore, from the perspective of AT research itself, there is still limited awareness and focus on mental workload, with most studies primarily concentrating on the physical effort aspect (Cahyanto & Nugraha, 2023; Izzhati, 2010) or subjective measurement on AT mental workload. Therefore, this study aims to establish a relationship between mental workload and the design of AT by employing physiological measurement tools such as a heart rate monitor (HRM).

Methods

Participants

Eleven proficient operators (3 females, 8 males) were enlisted on a voluntary basis to engage in this experiment (mean age 35.27 ± 15.3 SD) based on either of the following criteria: a minimum of 5 years of experience or a recommendation from colleagues or superiors (Plamondon et al., 2014). All participants were in good physical condition, right-handed, and had either normal vision or vision that had been corrected. Before the experiment, participants were informed to ensure they had sufficient rest and refrained from consuming coffee and cigarettes. Prior to their participation, all participants read and provided their signatures on a consent form. The experiment was designed to examine the mental workload experienced while using AT.

Procedure

This experiment is categorized as a within-subject design, where each participant will operate two different AT machines: Customized and Commercial Extruder. Customized Extruder is a noodle maker machine developed by a research institution. Customized Extruder has a larger capacity, is equipped with a heater for flour pre-gelatinization, and has a specially designed screw configuration to improve noodle quality. Commercial Extruder is a commercially available extruder with a smaller capacity and lacks a heater. Both machines serve the same purpose, which is to shape non-wheat flour dough into noodle strands. As shown in Table 1, both machines follow the same sequence, but the Customized Extruder involves several additional sub-steps, such as installing dies, a hopper, and waiting time.

Table 1. Extruder operation stages

<table>
<tr><th>Step</th><th>Customized</th><th>Commercial</th></tr>
<tr><td rowspan="2">1</td><td colspan="2">Installing and tightening the screw</td></tr>
<tr><td>Installing dies onto the locking flange and plugging in the hopper</td><td></td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Supplying electricity and turning on the machine</td></tr>
<tr><td>Waiting for the temperature to reach 50 degrees</td><td></td></tr>
<tr><td>3</td><td colspan="2">Inserting the dough mixture</td></tr>
<tr><td>4</td><td>Removing the hopper and turning off the machine</td><td>Turning off the machine</td></tr>
<tr><td>5</td><td colspan="2">Unlocking the dies</td></tr>
<tr><td>6</td><td colspan="2">Removing the screw</td></tr>
<tr><td>7</td><td colspan="2">Cleaning up any remaining dough</td></tr>
</table>

Both machines differ in terms of design, with the Customized Extruder categorized as a machine with a non-ergonomic design and the Commercial Extruder categorized as a machine with a design that approaches ergonomics. This statement is based on the results of a questionnaire filled out by 10 experts in the field of AT, where the questionnaire considered the following 6 aspects: (1) safety and error prevention, (2) functionality and cost-effectiveness, (3) user-friendliness, (4) low physical effort, (5) compatibility with the physical workspace, and (6) clarity of information. Previous research conducted by Indriati et al (2022) on Customized Extruder indicated that the machine did not meet ergonomic criteria based on biomechanical aspects. Commercial Extruder is commercially available and is categorized as approaching ergonomic criteria. Therefore, further research is conducted to assess the mental workload aspect. Additionally, machine categorization also involves expert assessments through the distribution of questionnaires to AT researchers who understand the functions and operation of

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both machines. Figure 1 depict customized extruder and Figure 2 depict commercial extruder.

Figure 1. Customized extruder

Figure 2. Commercial extruder

The implementation of the experiment includes: The participants were asked to allocate 2 hours at the Testing Room in the Center for Appropriate Technology Research - National Research and Innovation Agency, Subang. The activities involved in this session included explaining the participants' tasks, filling out an informed consent form, completing a biodata form, receiving instructions on operating the machine, and trying out the machine for approximately 30 minutes. HRV Garmin sensors will also be attached to measure heart rate variability (HRV) data. The experiment will begin with a 5-minute baseline data collection, followed by operating the machine for approximately 60 minutes for the Customized Extruder or 45 minutes for the Commercial Extruder (both machines were operated on different days). A counterbalance was done to avoid any learning effect by dividing the participants into two groups. The first group will operate the commercial extruder machine first, and the second group will operate the customized extruder machine first. After the experiment, participants will be instructed to sit and relax for a period of rest measurement. The data collected from the participants will consist of heart rate data.

Assessment of Mental Workload

The Garmin HRM Pro device is utilized as a data collection tool. This device is designed in the form of a belt that is worn around the chest, and it requires direct contact with the skin. The section in direct contact with the skin is equipped with sensors capable of measuring heart rate. The HRM Pro device will transmit real-time heart rate visualizations to a connected device through Bluetooth. The data is recorded and can be downloaded for further analysis. The Kubios HRV Standard software serves as a tool for analyzing heart rate data. Kubios HRV Standard provides flexibility for data segmentation. In this experiment, data segmentation is performed at the initial 5 minutes, after each step (there are 7 steps), and the final 5 minutes, providing opportunities for further analysis.

`The heart rate data from all participants were subject to analysis, considering six parameters. Among these parameters, three were in the time domain (SDNN, RMSSD, and pNN50), while the remaining three were in the frequency domain (low frequency (LF), high frequency (HF), and LF/HF ratio). These six parameters were selected based on their common usage in research concerning mental workload and their recognized sensitivity as reliable parameters (Tao et al., 2019). Further explanations regarding each parameter can be found in Table 2 (Hao et al., 2022).

In several scenarios as shown in driving (Heine et al., 2017) and traffic density monitoring (Fallahi et al., 2016), a decrease in the values of LF, HF, pNN50, RMSSD, and SDNN indicated an increase in mental workload. Conversely, the LF/HF ratio increased with increased mental workload, such as cognitive performance (Abbasi et al., 2022) and task complexity (Hwang et al., 2008) scenarios. These findings enhance our comprehension of the connection between physiological measurements and mental workload within the experiment's context.

Table 2. Explanation of HRV parameters

Parameter	Description
SDNN (ms)	The standard deviation of RR intervals
RMSSD (ms)	The root mean square of the difference between adjacent RR interval
pNN50 (%)	The ratio of the NN50 to the number of RR intervals
LF (ms^2)	Low-frequency power (0.04-0.15 Hz)
HF (ms^2)	High-frequency power (0.15-0.4 Hz)
LF/HF (ms^2)	Sympathetic to vagal ratio

Statistical Analysis

Classical assumption testing was performed in the form of normality tests for each stage of machine usage across each parameter, with significance levels above 0.05 being categorized as having a normal distribution. Subsequently, a test for mean differences was conducted. If the data were found to follow a normal distribution, a paired t-test was employed (sig.: <0.05). Conversely, if the assumption was not met, a Wilcoxon ranked-test was conducted (sig.: <0.05) (Walpole, et al., 2012). IBM SPSS Statistics 25 was utilized for these analyses.

Results

The raw participants data is presented in the form of the difference in values from customized extruder minus commercial extruder. The differences in SDNN values are displayed in Figure 3. Figure 4 presents the differences for RMSSD, while the variation in pNN50 values can be seen in Figure 5. The LF value differences are illustrated in Figure 6, followed by the HF value differences in Figure 7. Lastly, Figure 8 shows the differences in the LF/HF ratio. The attachment of this raw data is expected to provide an overview of the difference between the two machines.

Once all participant data had been successfully measured, normality testing using the Kolmogorov-Smirnov test was conducted for each parameter and each step (a total of 7 steps). The normality test is conducted to identify the subsequent test that is appropriate for the data distribution. This test determines whether the data conforms to a normal distribution. One of the outcomes of the normality test for the SDNN parameter can be observed in Table 3. Among the 6 HRV parameters subjected to normality testing, only the SDNN parameter exhibited a normal distribution (sig.>0.05) in both machines and across all steps. Conversely, the parameters of the RMSSD, pNN50, LF, HF, and LF/HF ratio displayed non-normal distributions, thereby warranting classification as nonparametric data (Walpole et al., 2012). Subsequently, a test for mean differences was conducted.

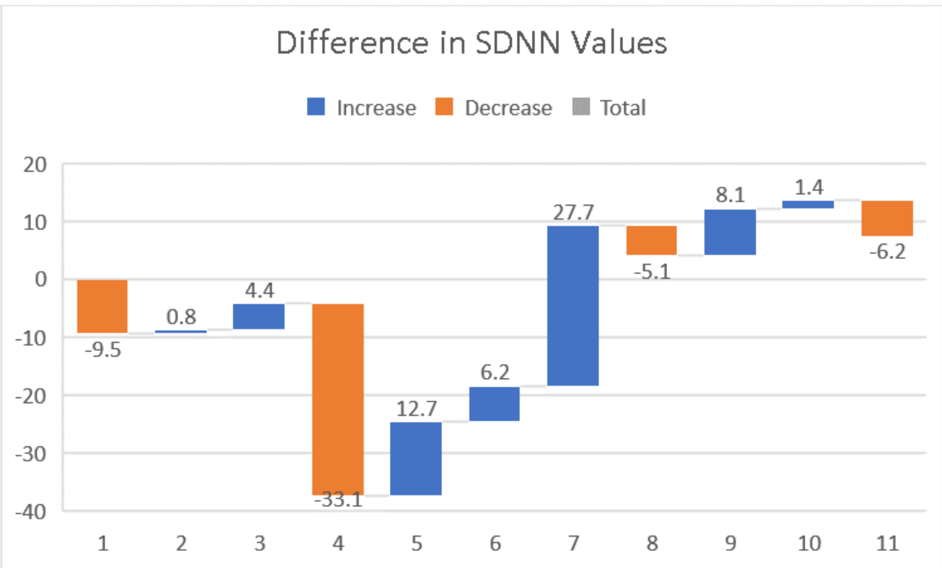

Figure 3. Difference in SDNN values

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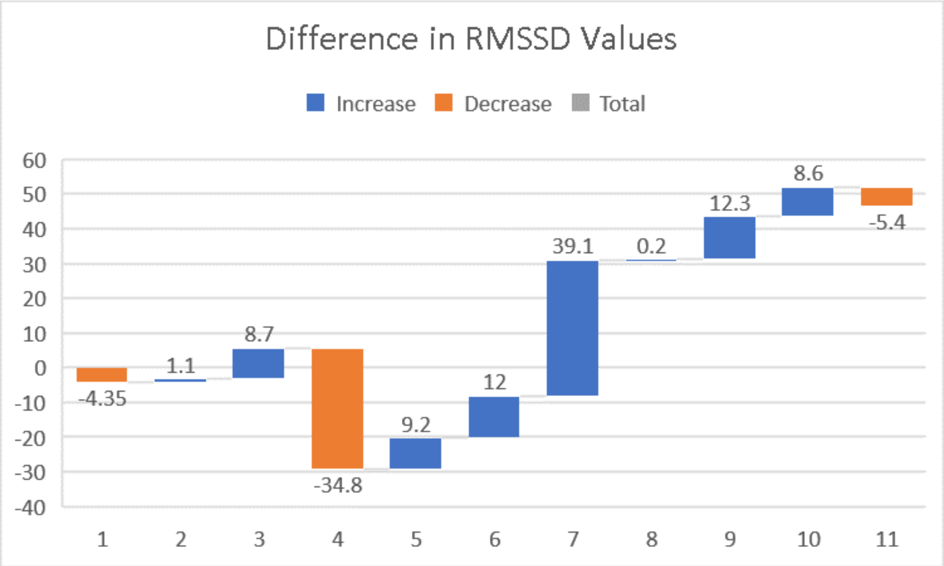

Figure 4. Difference in RMSSD values

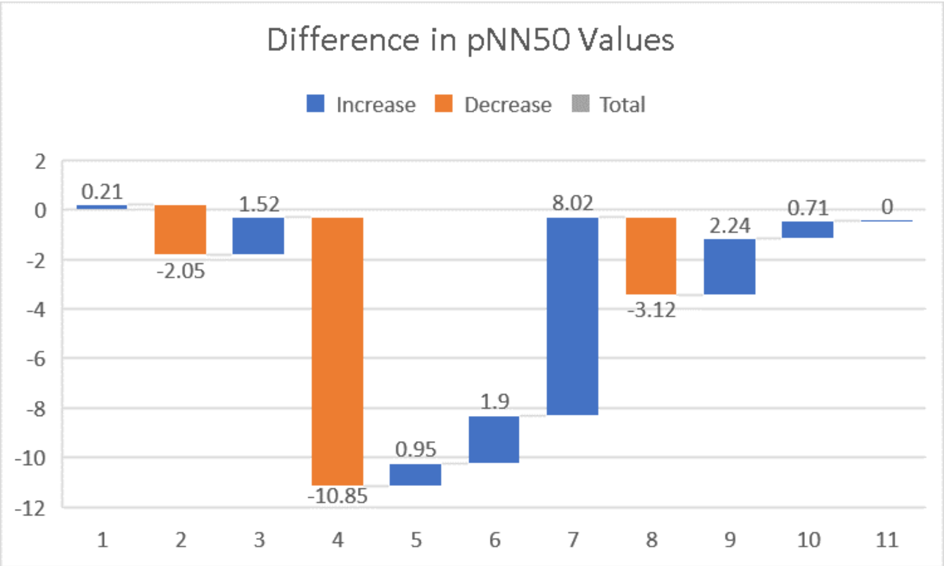

Figure 5. Difference in pNN50 values

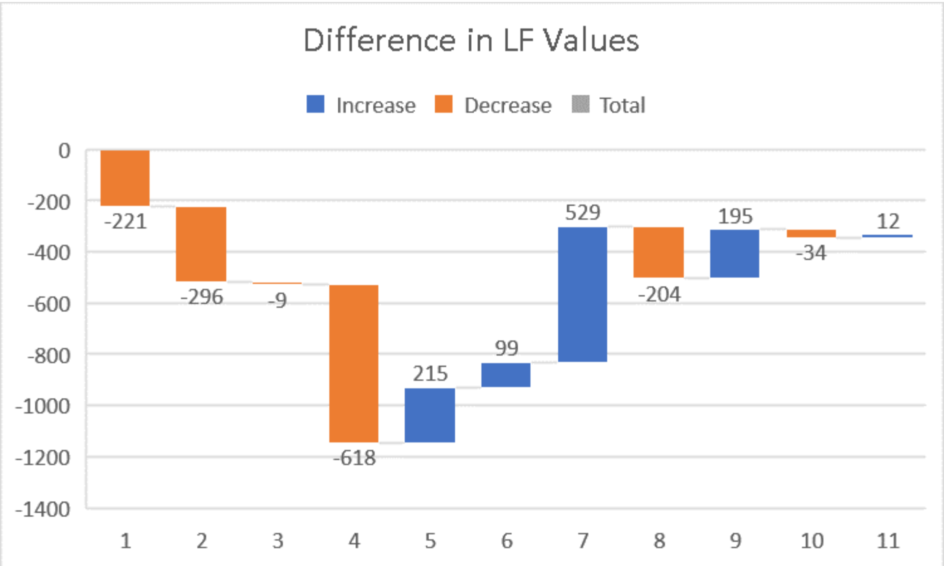

Figure 6. Difference in LF value

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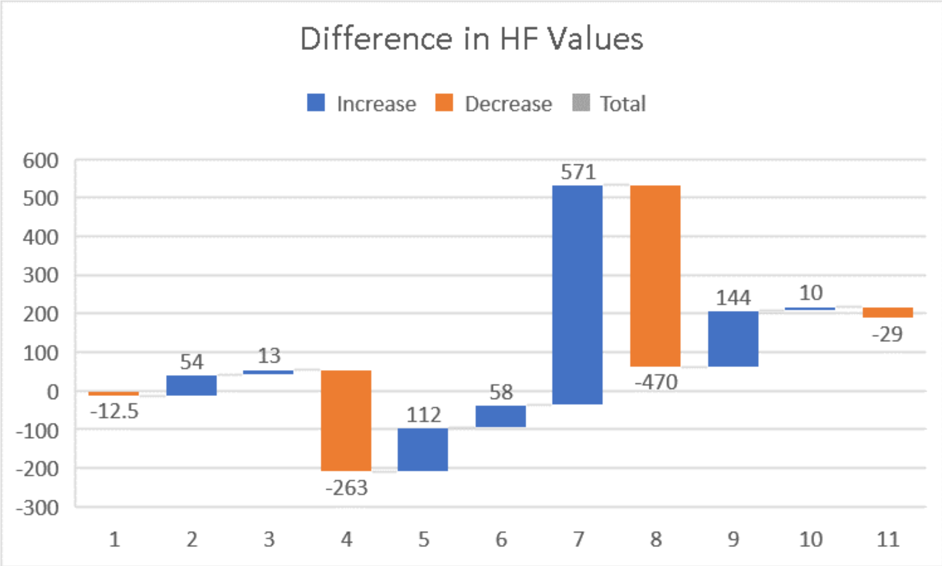

Figure 7. Difference in HF values

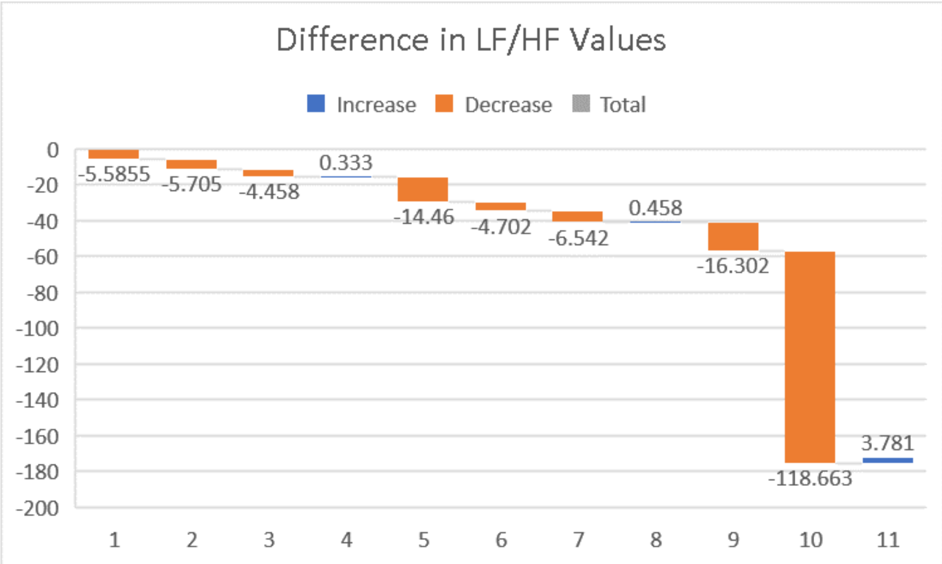

Figure 8. Difference in LF/HF values

Table 3. Examples of normality tests (*1_2 refers to customized extruder, operation stage 2)

Parameter	Df	Sig.
SDNN1_1	11	0.200
SDNN1_2*	11	0.200
SDNN1_3	11	0.200
SDNN1_4	11	0.171
SDNN1_5	11	0.200
SDNN1_6	11	0.200
SDNN1_7	11	0.080
SDNN2_1	11	0.065
SDNN2_2	11	0.200
SDNN2_3	11	0.050
SDNN2_4	11	0.200
SDNN2_5	11	0.074
SDNN2_6	11	0.200
SDNN2_7	11	0.058

The Wilcoxon signed-rank test works by observing whether a value decreases or increases compared to a previous value without considering the actual magnitude of the difference between the two groups. This difference is then represented in the form of positive and negative rankings. The more significant the difference between the positive and negative rankings, the more significant the observed difference becomes (Walpole et al., 2012). The results of the positive and negative rankings can be seen in Figure 3 until Figure 8.

Among all the mean difference tests performed for each parameter and each step, the LF/HF ratio demonstrated a significant mean difference (sig.<0.05) in the first step tested by Wilcoxon signed-rank test that presents in Table 4. The difference is also

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reflected in the ranking graph of the LF/HF ratio parameter, as illustrated in Figure 9.

Discussion

This study aims to determine the presence of differences in mental workload experienced by participants when using two different machines with distinct designs, despite having the same function. This research also identifies which HRV parameters are sensitive to changes in mental workload during the execution of the AT machine operational scenarios. In this study, we have found that there is a difference between both AT, particularly during the first step. The HRV parameter capable of detecting this change is the LF/HF ratio, similar to the findings of the study by Heine et al (2017), where mental workload was also detected using the LF/HF ratio.

Table 4. Examples of normality tests (*1_2 refers to customized extruder, operation stage 2)

Machine Comparison per-Step	Sig.
2_1-1_1	0.016
2_2-1_2	0.213
2_3-1_3	0.722
2_4-1_4	0.722
2_5-1_5	0.110
2_6-1_6	0.722
2_7-1_7	0.328

Several parameters in the frequency domain exhibit correlations with parameters in the time domain. Specifically, HF (high frequency) correlates with RMSSD, also considered a parasympathetic activity descriptor. In contrast, LF (low frequency) represents sympathetic activity. Therefore, the LF/HF ratio is a significant parameter, as it delineates the balance between sympathetic and parasympathetic activities (Heine et al., 2017; Malik, 2006). An escalation in mental workload is strongly linked to a rise in the LF/HF ratio. The sympathetic nervous system is commonly linked to stress, while the parasympathetic nervous system is associated with relaxation. When the sympathetic nervous system is more active than the parasympathetic nervous system, this can influence the LF values and result in an elevated LF/HF ratio.

Figure 3 until Figure 8 shows a notable difference between positive and negative ranks in every parameter. According to Walpole, et al., (2012), if the positive rank exceeds the negative rank, it can be inferred that there is a tendency to increase from the first group to the second group, where the first group corresponds to the Commercial Extruder. The second group corresponds to the Customized Extruder. This implies an increase in the LF/HF ratio value from using the Commercial Extruder to the customized Extruder, corresponding with an escalation in mental workload. These findings align with several other studies in different scenarios, such as cognitive performance under noise exposure (Abbasi et al., 2022), operator of Traffic Control Center (Fallahi et al., 2016), and office work (Cinaz et al., 2010).

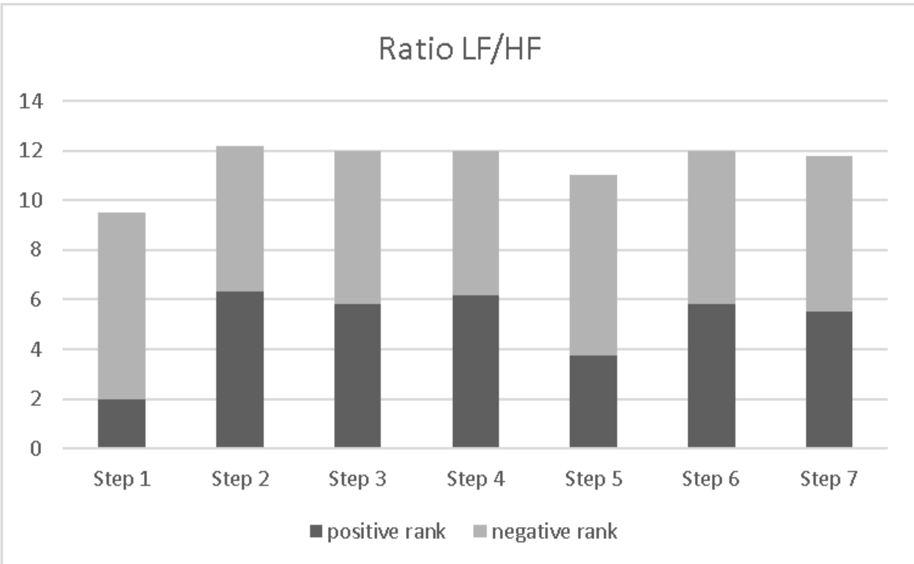

Figure 9. Ranking of ratio LF/HF for each step

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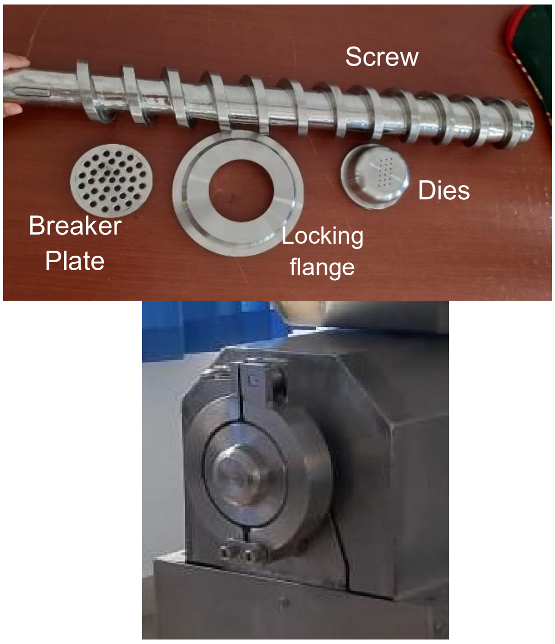

Figure 10. Customized extruder tools for step 1

In a more detailed explanation, Figure 10 represent a step 1 for Costumized Extruder which the process involves inserting the screw into the machine, attaching the breaker plate, and assembling the dies onto the locking flange. Subsequently, all components are securely fastened. Conversely, for the Commercial Extruder, which represented by Figure 11, the process entails inserting the screw into the machine, fitting the dies by applying pressure, and then installing the breaker plate, which is tightened using a threading mechanism. Figure 10 show a process of attaching dies to the Customized Extruder after the screw is inserted. This die attachment involves two components that must be assembled into one unit. This assembly process is time-consuming and mentally demanding due to the poorly fitting die design, requiring multiple attempts to ensure proper alignment. This is reinforced by contrasting the duration each participant spent in Step 1 for both machines. The average time was 3 minutes and 44 seconds for the customized Customized Extruder and 1 minute and 49 seconds for the Commercial Extruder, respectively. The statistical analysis conducted (utilizing the Wilcoxon signed-rank test) revealed a significant difference (sig. <0.05) between the two durations, with the Commercial Extruder having a smaller value, indicating a shorter time requirement. The time needed is longer because the customized extruder has a longer screw, and researchers specifically designed its configuration to produce quality non-wheat noodles. This is in line with several previous studies on AT machines that still focus on functional and technical aspects. On the other hand, Commercial Extruder is designed for marketing and complies with appropriate standards for mass production. The components of Commercial Extruder are assembled using threads, which means that after inserting the screw, operators attach the dies and breaker plate through a thread assembly process.

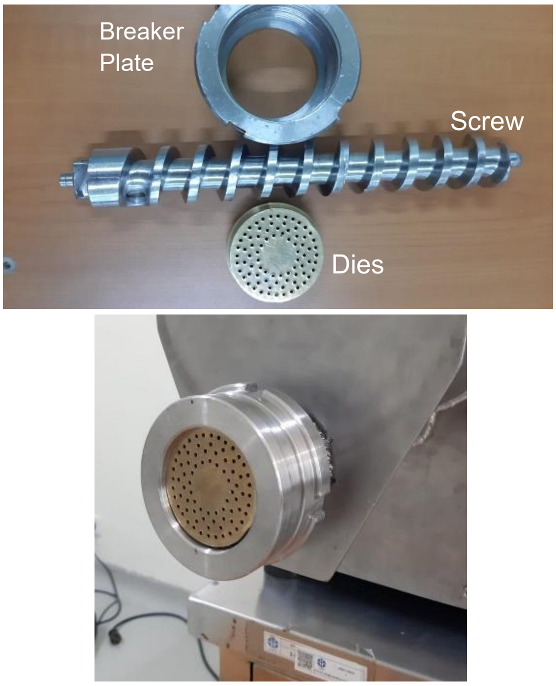

Figure 11. Commercial extruder tools for step 1

Conclusion

This study investigates the differences in perceived mental workload among operators when using two different ATs. The researchers created the customized AT, whereas the Commercial AT is readily available for bulk purchase. It was observed that operators experienced a higher mental workload when using the customized AT, particularly during step 1. The parameter detecting this discrepancy originates from the frequency domain, specifically the LF/HF ratio. These findings offer valuable insights for researchers in ATs, as they have a personal understanding of the needs of Small and Medium-sized Enterprises (SMEs) through collaborative programs.

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References

Abbasi, A. M., Darvishi, E., Rodrigues, M. A., & Sayehmiri, K. (2022). Gender differences in cognitive performance and psychophysiological responses during noise exposure and different workloads. *Applied Acoustics*, *189*. https://doi.org/10.1016/j.apacoust.2021.108602

Cahyanto, W. E., & Nugraha, A. E. (2023) *Analisis Postur Pekerja Menggunakan Metode Rapid Upper Limb Assessment pada UMKM Kerupuk Setuju*. *VIII*(1), 4381–4387.

Causse, M., Fabre, E., Giraudet, L., Gonzalez, M., & Peysakhovich, V. (2015). EEG/ERP as a Measure of Mental Workload in a Simple Piloting Task. *Procedia Manufacturing*, *3*, 5230–5236. https://doi.org/10.1016/j.promfg.2015.07.594

Charles, R. L., & Nixon, J. (2019). Measuring mental workload using physiological measures: A systematic review. In *Applied Ergonomics* (Vol. 74, pp. 221–232). Elsevier Ltd. https://doi.org/10.1016/j.apergo.2018.08.028

Choi, M. K., Lee, S. M., Ha, J. S., & Seong, P. H. (2018). Development of an EEG-based workload measurement method in nuclear power plants. *Annals of Nuclear Energy*, *111*, 595–607. https://doi.org/10.1016/j.anucene.2017.08.032

Cinaz, B. L., Marca, R., Arnrich, B., & Tröster, G. (2010). Monitoring of Mental Workload Levels. *IADIS International Conference e-Health* 189–193. https://doi.org/10.5167/uzh-66793

Collet, C., Salvia, E., & Petit-Boulanger, C. (2014). Measuring Workload With Electrodermal Activity During Common Braking Actions. *Ergonomics*, *57*(6), 886–896. https://doi.org/10.1080/00140139.2014.899627

Fallahi, M., Motamedzade, M., Heidarimoghadam, R., Soltanian, A. R., & Miyake, S. (2016). Effects of Mental Workload on Physiological and Subjective Responses During Traffic Density Monitoring: a Field Study. *Applied Ergonomics*, *52*, 95–103. https://doi.org/10.1016/j.apergo.2015.07.009

Ghanavati, F. K., Choobineh, A., Keshavarzi, S., Nasihatkon, A. A., & Roodbandi, A. S. (2019). Assessment of Mental Workload and Its Association With Work Ability in Control Room Operators. *National Library of Medicine*, *110*(5), 389–397.

Hao, T., Zheng, X., Wang, H., Xu, K., & Chen, S. (2022). Linear and Nonlinear Analyses of Heart Rate Variability Signals Under Mental Load. *Biomedical Signal Processing and Control*, *77*. https://doi.org/10.1016/j.bspc.2022.103758

Heine, T., Lenis, G., Reichensperger, P., Beran, T., Doessel, O., & Deml, B. (2017). Electrocardiographic Features for The Measurement of Drivers' Mental Workload. *Applied Ergonomics*, *61*, 31–43. https://doi.org/10.1016/j.apergo.2016.12.015

Hwang, S. L., Yau, Y. J., Lin, Y. T., Chen, J. H., Huang, T. H., Yenn, T. C., & Hsu, C. C. (2008). Predicting Work Performance in Nuclear Power Plants. *Safety Science*, *46*(7), 1115–1124. https://doi.org/10.1016/j.ssci.2007.06.005

Indriati, A., Mayasti, N.K.I., Rahman, T., Litaay, C., Anggara, C.E.W., Astro, H.M., Surahman, D.N., Novianti, F., Andriana, Y. 2022. Risk analysis of Musculoskeletal Disorder (MSDs) on corn noodles production. *The 4th International Conference on Food and Agriculture. IOP Conf. Series: Earth and Environmental Science 980*. 1-9. doi:10.1088/1755-1315/980/1/012048

Irawan, D., Azhar., Sahal, M. (2020). Ergonomic Design of Weeds Sparyer Based on Recycle Energy to Support Palm Oil Replanting. *Journal of Innovation and Creatiivity Resource* Vol 1 (1). 13-20

Izzhati, D. N. (2010). Pengembangan Alat Pemotong Tahu yang Ergonomis dengan Menggunakan Metode RULA. *Prosiding Seminar Nasional Sains dan Teknologi, 1*(1),1-5. doi:http://dx.doi.org/10.36499/psnst.v1i1.325.

Malik, M. (1996). Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use. *Circulation, 93*(5), 1043-1065.

Maulid, M. R., Hanifah, A., Fakhira, N. V., Fajriansyah, M. R., Rahmah, D. M. (2019). Identifikasi Pengaturan Sistem Kerja pada Pengolahan Kopi Proses natural dengan Analisis Penanganan Bahan, Peta Kerja, Beban Fisiologis, dan Luas Lantai (Studi Kasus : IKM M45T3R AMMO Coffee. *Jurnal Industri Pertanian*)

Kementrian Investasi/BKPM. (2023). *Investment to Drive Digital Agriculture Practices in Indonesia*. Retrieved from Minihttps://Www.Bkpm.Go.Id/En/Publication/Detail/News/Investment-to-Drive-Digital-Agriculture-Practices-in-Indonesia.

Moses, N. D., Pakravan, M. H., & MacCarty, N. A. (2019). Development of a practical evaluation for cookstove usability. *Energy for Sustainable Development*, *48*, 154–163. https://doi.org/10.1016/j.esd.2018.12.003

Parasuraman, R., & Mouloua, M. (2018). *Automation and Human Performance: Theory and Applications*. Boca Raton: Routledge.

Plamondon, A., Delisle, A., Bellefeuille, S., Denis, D., Gagnon, D., & Larivière, C. (2014). Lifting Strategies of Expert and Novice Workers During a Repetitive Palletizing Task. *Applied Ergonomics*, *45*(3), 471–481. https://doi.org/10.1016/j.apergo.2013.06.008

Qu, H., Gao, X., & Pang, L. (2021). Classification of Mental Workload Based on Multiple Features of ECG Signals. *Informatics in Medicine Unlocked*, *24*. https://doi.org/10.1016/j.imu.2021.100575

Radhakrishnan, V., Louw, T., Cirino Gonçalves, R., Torrao, G., Lenné, M. G., & Merat, N. (2023). Using Pupillometry and Gaze-Based Metrics for Understanding Drivers' Mental Workload During Automated Driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *94*, 254–267. https://doi.org/10.1016/j.trf.2023.02.015

Rahayuningtyas, A., & Afifah, N. (2016). Rancang Bangun, Uji Performa dan Analisa Biaya Pengeringan Irisan Singkong Menggunakan Pengering Inframerah. *Jurnal Pangan,* *25*(1), 1-70. doi:https://doi.org/10.33964/jp.v25i1.30

Reyes del Paso, G. A., Langewitz, W., Mulder, L. J. M., van Roon, A., & Duschek, S. (2013). The Utility of Low Frequency Heart Rate Variability as an Index of Sympathetic Cardiac Tone: a Review With Emphasis on A Reanalysis of Previous Studies. *Psychophysiology* (Vol. 50, Issue 5, pp. 477–487). Blackwell Publishing Inc. https://doi.org/10.1111/psyp.12027

Sianipar, C. P. M., Yudoko, G., Adhiutama, A., & Dowaki, K. (2013). Community Empowerment through Appropriate Technology: Sustaining the Sustainable Development. *Procedia Environmental Sciences*, *17*, 1007–1016. https://doi.org/10.1016/j.proenv.2013.02.120

Siswandi., Nugroho, L. (2020). Pengembangan Desain Mesin Teknologi Tepat Guna Pada Proses Produksi Opak Jepit Berbasis Ergonomis dan Keinginan Konsumen dengan Metode QFD. *CIASTECH 2020.* 499-508

Stasi, L. L., Antolí, A., & Cañas, J. J. (2013). Evaluating Mental Workload While Interacting With Computer-Generated Artificial Environments. *Entertainment Computing*, *4*(1), 63–69. https://doi.org/10.1016/j.entcom.2011.03.005

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 (15). https://doi.org/10.3390/ijerph16152716

Taofik, I. M., & Mauluddin, Y. (2015). Evaluasi Ergonomi Menggunakan Metode RULA (Rapid Upper Limb Assessment) untuk Mengidentifikasi Alat Bantu Pada Mesin Roasting Kopi. *Jurnal Kalibrasi, 13*(1), 1-14. doi:https://doi.org/10.33364/kalibrasi/v.13-.204

Tran, T. Q., Boring, R. L., Dudenhoeffer, D. D., Hallbert, B. P., David Keller, M., & Anderson, T. M. (n.d.). *Advantages and Disadvantages of Physiological Assessment for Next Generation Control Room Design*.

Venkatesh, V., & Davis, F. D. (2000). Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, *46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Walpole, R. E., Myers, R. H., Myers, S. L., & Ye, K. (2012). *Probability & Statistics for* *engineers & scientist* (Vol. 9). Boston: Pearson.

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). State of Science: Mental Workload in Ergonomics. *Ergonomics*, 58 (1), 1–17. Taylor and Francis Ltd. https://doi.org/10.1080/00140139.2014.956151