INVESTIGATION ON HEART RATE VARIABILITY INDICES AND MENTAL STRESS IN PERFORMANCE WITH FRACTIONS: A STUDY IN THE FINAL YEARS OF ELEMENTARY SCHOOL IN FLORIANÓPOLIS-SC

INVESTIGAÇÃO SOBRE ÍNDICES DE VARIABILIDADE DA FREQUÊNCIA CARDÍACA E ESTRESSE MENTAL NO DESEMPENHO COM FRAÇÕES: UM ESTUDO NOS ANOS FINAIS DO ENSINO FUNDAMENTAL EM FLORIANÓPOLIS-SC

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Ana Elisa Pillon [a], Vânia Ribas Ulbricht [b], Márcio Vieira de Souza [c]

[a] Universidade Federal de Santa Catarina UFSC – PPGEGC, Brasil; pillon.anaelisa@gmail.com; [b] Universidade Federal de Santa Catarina UFSC – PPGEGC, Brasil; vrulbricht@gmail.com; [c] Universidade Federal de Santa Catarina UFSC – PPGEGC, Brasil; marciovieiradesouza@gmail.com

ABSTRACT

Anxiety and stress, although distinct, are interconnected and mutually influence each other. Mathematical anxiety, common in the educational environment, brings discomfort and concern when dealing with mathematical concepts or tasks. In this study of applied nature, technological modality, and mixed approach, field research was conducted in municipal schools with students from the final years of elementary school, and the instruments used were semi-structured interviews and collection of Heart Rate Variability (HRV) variables, aiming to analyse students' mental stress levels during fraction exercises and their possible relationship with mathematical anxiety. The results indicated that 49% of students, the majority, experienced the highest levels of stress during exercise completion. Considering the relevance of the findings, it is recommended to conduct further research to enhance the use of HRV analysis to assist in the teaching-learning process of mathematics.

Keywords: Learning, mathematics, Heart Rate Variability (HRV), stress, anxiety math

RESUMO

Ansiedade e estresse, embora distintos, estão interligados e influenciam-se mutuamente. A ansiedade matemática, comum no ambiente educacional, traz desconforto e preocupação ao lidar com conceitos ou tarefas matemáticas. Neste estudo de natureza aplicada, modalidade tecnológica e abordagem mista, realizou-se pesquisa de campo em escolas municipais com estudantes dos anos finais do ensino fundamental e os instrumentos foram entrevistas semiestruturadas e coleta de variáveis da Variabilidade da Frequência Cardíaca (VFC), tendo por objetivo analisar os índices de estresse mental dos estudantes durante a realização de exercícios com frações, e sua possível relação com a ansiedade matemática. Os resultados indicaram que 49% dos estudantes, a maioria, experienciou os maiores índices de estresse durante a realização de exercícios. Considerando a relevância dos achados, é recomendável a condução de novas pesquisas com o intuito de aprimorar a utilização da análise da VFC para auxiliar no processo de ensino-aprendizagem da matemática.

Palavras-chave: Aprendizagem, matemática, Variabilidade da Frequência Cardíaca (VFC), estresse, ansiedade matemática

1. INTRODUCTION

Mathematics plays a fundamental role in the education of students (Silva, 2017). Through this discipline, students acquire essential skills such as counting, measuring, and problem-solving, which are considered elementary for personal and professional development and integration into society. According to the National Common Curricular Base (NCCB), the various domains that make up the mathematics discipline provide a set of fundamental concepts that, when intertwined, play a crucial role in the development of students' mathematical thinking (Brazil, 2018).

However, learning mathematics has become a challenge for many students, who often express the phrase "I am not good at math" even before attempting to solve the proposed questions (Segarra & Julià, 2021; Colomeischi & Colomeischi, 2015). Thus, mathematics represents a significant barrier for most students, as the stigma of it being a difficult subject persists regardless of the level of schooling (Oliveira & Oliveira, 2017).

Analyzing the contents covered in the subject, the topic of "fractions" represents one of the most significant areas of mathematics in elementary school, as understanding fractions will lead students to succeed in algebra. However, it remains one of the topics that cause the most difficulties throughout people's school lives. Many students consider this topic to be "easy" and therefore do not pay the necessary attention to understanding the content. As a result, the difficulties persist and perpetuate over time and even into adulthood (Fonseca & Santos, 2019).

According to Herreras (2018), mathematical competence can cause anxiety, stress, and even a sense of helplessness in young people. The inclination towards low performance can be attributed to anxiety, as well as factors still under investigation, such as delays and deficits in neurocognitive processes.

Concurrently with this theme, mental or emotional stress has been identified as one of the main challenges in contemporary societies (Loures et al., 2002). High levels of stress can be associated with the onset of anxiety, especially in predisposed individuals. Just as with other types of anxiety, math anxiety encompasses a variety of complex dimensions, which manifest through cognitive, affective, somatic, and behavioral reactions. Therefore, math anxiety (MA) describes feelings of tension, apprehension, and fear that this feeling may interfere with mathematics performance. High MA is correlated with negative consequences, including lower math grades and, ultimately, an avoidance of quantitative careers (Pizzie et al., 2020).

Given the above, this article presents an excerpt from a study whose general objective was to identify the state of the teaching-learning process of mathematics among students from the 6th to the 9th grades of elementary school in public schools in Florianópolis-SC. Additionally, specific objectives were defined, among which the one presented in this article: To recognize how mental stress indices, evaluated by heart rate variability, can be used to analyze students' performance in solving fractions exercises. In this sense, the question that drove this study was: How did students' mental stress levels manifest during the completion of fractions exercises?

In order to achieve this objective, this article will present the following topics: (ii) theoretical framework, (iii) methodology used, (iv) results and discussion, and finally, (v) final considerations and indications for future studies.

2. Theoretical Framework

2.1 Mental Stress and Math Anxiety

According to Margis et al. (2003), stress is defined as a state triggered by the perception of stimuli that provoke emotional arousal and interfere with the body's homeostasis. This state initiates an adaptation process characterized by various changes, including increased adrenaline secretion, resulting in systemic manifestations that cause physiological and psychological disturbances. Thus, in response to a stressful situation, the human body reallocates its energy reserves in preparation for a possible immediate threat (Loures et al., 2002).

According to Omar et al. (2022), performance in mathematics has been a driving force in students academic achievement worldwide. Therefore, researchers have conducted a series of studies to explore the connection between these levels and math anxiety (Herreras, 2018; Omar, Aris, Hoon, 2022). The states of anxiety pointed out by the authors highlight physiological and behavioral reactions such as tense posture, headaches, stomach disturbances, uncoordinated movements, and sweaty hands, among others. However, in addition to these, behavioral and cognitive outcomes may arise, including reports of unpleasant sensations in situations where escape is impossible, anticipation of punishment, and separation from social support, such as family or close friends.

In this sense, a student with anxiety related to mathematics may face difficulties concentrating when doing homework, exhibit aggression when questioned by the teacher in the classroom, and experience tachycardia during exams in this subject. These physiological reactions can negatively impact the student's performance in mathematical tasks, both now of anxiety and in future activities, such as college entrance exams or daily situations. Confirming the seriousness of the situation, for Moura-Silva et al. (2020), math anxiety has become a global and prevalent phenomenon, and thus, studies that can indicate educational practices to help students regulate their emotions regarding mathematics will contribute to the teaching-learning process essential for the personal and professional development of all.

2.2 Heart Rate Variability (HRV) As An Aid In The Cognitive Process

Heart Rate Variability (HRV) is a measure that evaluates the fluctuations in the interval between two consecutive heartbeats, known as RR intervals. These intervals represent the time elapsed between two R peaks identified on the electrocardiogram (ECG) (Thayer, Lane & Bernard, 2009). According to Vanderlei et al. (2009), changes in HRV are considered normal and expected and indicate the heart's ability to respond to different physiological or environmental stimuli, which include: breathing, physical exercise, stress, sleep, disorders resulting from diseases, among other factors.

According to Thayer (2007), HRV analysis can be useful in the educational context, as it allows the collection of relevant cognitive indicators for this process. Sgobbi et al. (2019) reinforce this position by addressing the use of Heart Rate Variability (HRV) for educational purposes, highlighting that its analysis offers a viable alternative to identify cognitive signals and students' attention levels during the learning process.

3. Methodology

3.1 Research Design

This study, characterized as applied research, aims to generate knowledge with potential practical applications, addressing specific issues. Regarding its modality, it is classified as technological research, starting from existing knowledge to develop new materials, products, equipment, processes, systems, or services, or to improve existing ones (Silveira & Cordova, 2009). Adopting a mixed approach, it combines quantitative and qualitative data analysis in a single investigation. As observed by Creswell (2010), this technique involves collecting both numerical data and textual information, such as that from interviews, resulting in a database composed of qualitative and quantitative elements.

3.2. Participants

Fifty-five students were intentionally and non-probabilistically selected to participate in this study. However, due to the requirement of the Kubios software, responsible for HRV analysis, which requires a minimum of 5 minutes of collected data, students who did not meet this minimum time were excluded from the sample. Thus, the final sample consisted of thirty-seven students (n=37), as presented in Table 1.

Table 1 – Demographic Characteristics of the Participants

Variable		
Gender		
Female	20	54%
Male	17	46%
Age		
11 years	4	11%
12 years	7	19%
13 years	13	35%
14 years	8	22%
15 years	5	13%

Source: Research data (2024)

As shown in Table 1, the majority of the participants were female (54%), and in terms of age, the highest percentage (35%) was 13 years old.

3.3 Data Collection Instruments

Before using the heart rate monitor, the students filled out a standard questionnaire, in which they provided personal information, including medical history and medication use. All participants were considered to be in good health, and no conditions that could interfere with data collection were identified. The session with Inner Balance™ was conducted only after obtaining the Informed Consent Form signed by the parents or guardians, as well as by the student who voluntarily participated in the research.

A heart rate monitor, known as a frequency meter, was used as the main data collection instrument in this research. This device, sensitive to the heart's electrical activity, captures and transmits signals to a device that visualizes heart activity. Specifically for this study, the Inner Balance™ sensor was used, as shown in Figure 1.

Figure 1 – Inner Balance™ Sensor

Source: Heart (2024)

After presenting the research objectives and verifying the demographic and health data of the participants, they were individually taken to quiet rooms with adequate temperature and lighting for the use of the sensor, and equipped with comfortable chairs, where they received the Inner Balance™.

This procedure lasted an average of 25 to 30 minutes, divided into three distinct phases: phase 1 consisted of a rest period (for proper calibration of the device) standardized to 10 minutes, followed by the phases of mathematical activities, with phase 2 using the Fractus application and phase 3 involving the resolution of exercises on a printed sheet.

Initially, the data were examined using the software emWave Pro Plus® version 3.11 and then submitted to the software Kubios HRV Standard 3.5, which eliminates artifacts in the data and also produces a PDF document with the HRV indices derived from time-domain linear methods, frequency-domain methods, and the Stress Index (SI).

Presented as phase 3 of the HRV index collection of the students, in this stage, the students received a printed sheet containing exercises on the topic "fractions." These exercises are part of the Fractus application and are available in Appendix A. The topic "fractions" was chosen as the research theme because, in the diagnostic stage, this was identified by the students as the most challenging content in mathematics (Pillon et al., 2024). Based on the diagnostic results, the Fractus application was developed, providing activities on fractions in the form of learning objects that can be performed via web/mobile application on devices such as smartphones, tablets, or televisions, and also includes exercises that can be printed for completion (Galvão Filho, 2022).

It is important to note that, although three moments were analyzed during the Inner Balance™ application—rest (1), using Fractus on smartphones (2), and with the printed exercise sheet (3)—for this article, the focus was only on the rest data and the completion of exercises on the printed sheet. The data with Fractus (phase 2) were presented at a Congress in 2023 (Pillon et al., 2023).

3.4 Analysis Procedures

The collected data were analyzed using Pearson's Correlation Coefficient, which aims to quantify the linear relationship between two continuous variables, known as "Pearson's r" and expressed as R or ρ (Lopes, 2018). Based on the variable's "time" elapsed during the completion of fractions exercises on a printed sheet and the "stress index" observed in this stage, the calculated R value was 0.028. Additionally, according to the author, when the R value approaches "zero," it indicates high dispersion and an extremely weak positive linear relationship between the two variables.

It is also inferred from this result that the strength of the relationship is extremely weak, meaning that the variability of exercise time explains only 0.028% of the variability of the stress index, and thus, 99.972% of the variability of the stress index is not explained by exercise time. Therefore, this study shows little or no significant relationship between the time spent on the exercises and the stress index, suggesting that other factors not analyzed in this research may have a greater impact on the stress index than the time students took to complete the exercises.

3.5 Ethical Considerations

This research was submitted to the UFSC Research Ethics Committee (CEPSH) for evaluation to ensure the protection of participants, addressing concerns such as involuntary identification, inappropriate use of images, and fatigue resulting from participation in the proposed activities. With the approval by the Human Research Ethics Committee on the Brazil Platform under Opinion number 3.296.598, activities in the schools began after authorization from the responsible parties (principals or pedagogical coordinators), who signed the official letter sent by the Continuing Education Management (GFC) of the Florianópolis City Hall/SC, in accordance with Municipal Ordinances 116/2012 and 076/2014, authorizing the research to be conducted in the school environment. Following interviews with the responsible parties, activities with the students were conducted, with all participants signing the Informed Consent Form (ICF) to ensure the anonymity and confidentiality of the data, and minor students had the ICF signed by both themselves and their parents or guardians.

4. Results And Discussion

4.1 Analysis Of Students' Heart Rate Variability

Data collection took place between August and October 2022. Participants were instructed on the objectives and phases of the study. Then, phase 1 (rest) began, during which participants remained individually separated, in silence, with their eyes open. In phase 2, participants were given a cell phone with the Fractus app installed and were instructed to complete the proposed activities. In the third and final stage, called phase 3, participants completed the fractions exercises provided on a printed sheet.

Two linear HRV parameters were analyzed in this study: time domain and frequency domain. In the time domain, the mean of the RR intervals (Mean RR), representing the average of the collected RR intervals, and the rMSSD value, indicating the variation between consecutive intervals in the sample (i.e., the Root Mean Square of the Successive Differences between adjacent RR intervals), reflecting the parasympathetic activity of the Autonomic Nervous System (ANS), were examined. The Mean RR and rMSSD indices are discussed and presented as significant indicators in several studies (Loureiro, 2018; Matos, 2013; Madison, 2021; Hilgarter et al., 2021; Sbissa, 2014). Regarding the frequency domain, the analysis focuses on the ratio between the low-frequency (LF) and high-frequency (HF) components, represented by the acronym LF/HF, reflecting the relationship between the two main pathways of the ANS, the sympathetic and parasympathetic components, characterizing the sympathovagal balance in the heart. Table 2 presents the data regarding the averages of Mean RR, rMSSD, and the LF/HF ratio in the rest phase and phase 3.

Table 2 – Descriptive Statistics of HRV Data

Origin	**variable**	**rest**	**exercises**
time domain	*Mean* RR	695	687
	rMSSD	108	111
frequency domain	LF/HF	1.712	1.311

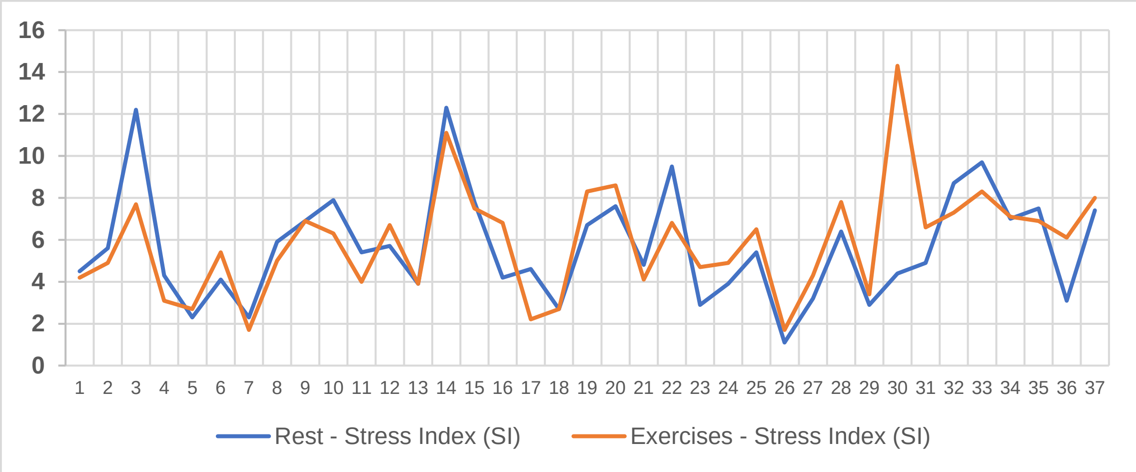
Source: Research data (2024)

According to Table 2, the students showed higher LF/HF indices during the rest phase. It is noteworthy that in this sympathovagal relationship, the higher the indices, the greater the association with the sympathetic system. In this context, during this study, this result can be attributed to the fact that the students were tense and anxious due to the expectation of participating in the research. The highest rMSSD average occurred during the exercises, suggesting greater activation of the parasympathetic system and lower activation of the sympathetic system, possibly due to fatigue, as this was the third stage of the study and subsequent productivity decline. Additionally, it is important to highlight that the students faced visible difficulties in performing the proposed activities in this phase, especially those related to operations with fractions, which they reported not having learned during the pandemic period. Regarding the Mean RR values, although in this article (excluding the Fractus phase), the highest index was observed during rest, during the analysis of the three phases, the highest value occurred during the use of Fractus, an aspect that confirms that when there is a higher HRV index and better performance, inhibitory stress control activation is also observed (Pillon et al., 2024).

4.2 Stress Index (SI) In HRV Analysis

Another index considered in this study is the Stress Index (SI), as defined in the Kubios HRV Standard User Guide (Tarvainen, Version 3.5), which represents a geometric measure of HRV reflecting the stress present in the cardiovascular system. Mental stress, the focus of this study, is a common occurrence in daily life and has been identified as a significant influencer in almost every aspect of our body, with the cardiovascular system being particularly affected. Recent research highlights that the physiological changes associated with stress include sympathetic hyperactivity and vagal inhibition, resulting in an imbalance in the regulation of the Autonomic Nervous System (ANS) and consequently contributing to the onset of ischemic and arrhythmic events. Figure 2 shows the students' stress indices (SI) obtained during rest and during exercises.

Figure 2 – Comparison of HRV Stress Index Scores - Rest vs. Exercises on Paper



Source: Research data (2024)

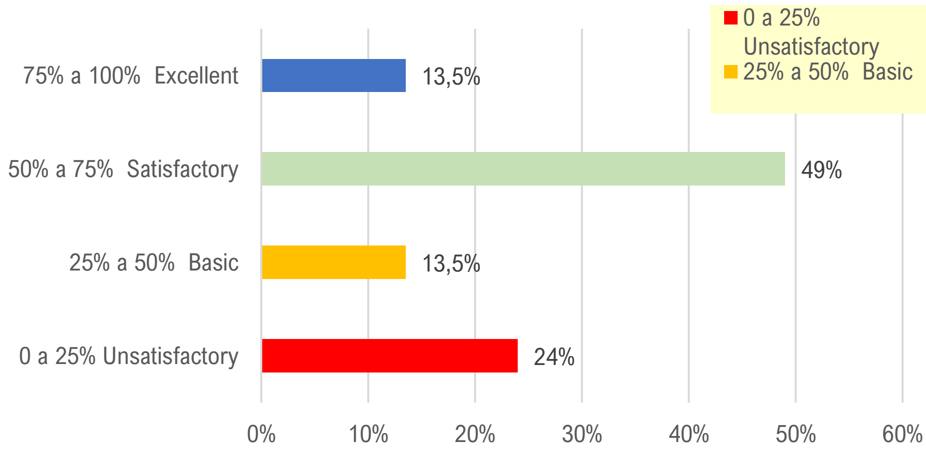
As shown in Figure 2, 43% of the students (15 participants) had a higher stress index during rest, and 22 participants (49% - the majority) showed a higher stress index during the completion of exercises. Additionally, there was a tie in the index with 3 students (8%). Regarding the high index during rest, a prolonged period dedicated to the rest phase can influence the participants' physiological response, making it tiring and causing stress (Loureiro, 2018). Furthermore, during the data collection for this research, it was noted that the students were anxious to perform the task, especially because it was an activity still unknown to them, as verbally reported by the participants.

Regarding the stress indices related to exercise completion, Carmo & Simionato (2012) emphasize that the occurrence of errors or low performance in solving exercises or incorrectly answering the teacher's questions can result in forms of aversive control. If this type of control is evident, it can become a cycle in which errors become more frequent, increasing aversive stimulation, which in turn can initiate the basis of anxiety related to mathematics.

4.3 PERFORMANCE IN COMPLETING FRACTION EXERCISES

The exercise sheet was offered to the students as an activity in phase 3 of data collection with the Inner Balance™ sensor. The participants took between 5 and 16 minutes to complete the activities, and the results are tabulated in Figure 3.

Figure 3 – Results of Students' Performance in the Exercises



Source: Research data (2024)

As illustrated in Figure 3, only 13.5% (5 students) achieved the highest score in the exercises; 49% (18 students) obtained a satisfactory score. Analyzing all "unsatisfactory" results, combining the students who were at the basic level and those who obtained an insufficient result, we would have a percentage of 37.5% of the total students, constituting a high result considering that the students completed the sheet right after recalling the contents with Fractus. The results thus confirmed the difficulties faced by the students in solving exercises, considering that during the pandemic period, inevitable gaps in learning were created.

5. CONCLUSION

This study investigated the mental stress indices of students during the completion of fraction exercises, as well as their possible relationship with math anxiety, using Heart Rate Variability (HRV) analysis. The results revealed that most students experienced the highest stress indices during the exercises, indicating an association between mathematical activity and increased mental stress. Additionally, it was observed that the students faced visible difficulties in solving the exercises, suggesting a possible influence of math anxiety on performance.

These findings highlight the importance of considering not only the cognitive aspect but also the emotional aspect of students during math teaching. Anxiety and stress can significantly impact students' academic performance and the quality of their learning. Therefore, teaching strategies aimed at reducing math anxiety and promoting students' emotional well-being are essential to ensure a healthy and productive learning environment.

It is suggested that future research further explore the relationship between math anxiety, mental stress, and academic performance, using longitudinal methods and larger samples. Additionally, investigations that assess the effectiveness of psychoeducational interventions aimed at reducing math anxiety and improving students' emotional regulation would be of great relevance. Moreover, considering the current context of remote and hybrid teaching, it is important to investigate how these teaching modalities affect students' math anxiety and stress, as well as to identify effective strategies to mitigate these negative impacts.

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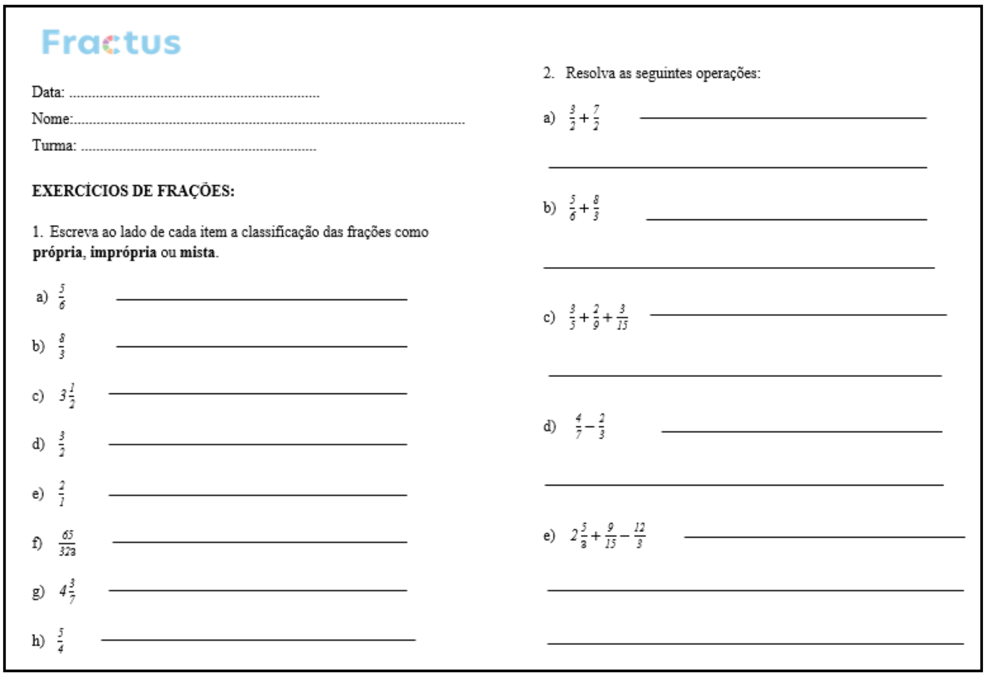
APPENDIX A – FRACTION EXERCISES SHEET (*FRACTUS*)



Fractus

Data: ....

Nome: ....

Turma: ....

EXERCÍCIOS DE FRAÇÕES:

1. Escreva ao lado de cada item a classificação das frações como **própria**, **imprópria** ou **mista**.

a) $\frac{5}{6}$ ____________

b) $\frac{8}{3}$ ____________

c) $3\frac{1}{2}$ ____________

d) $\frac{3}{2}$ ____________

e) $\frac{2}{1}$ ____________

f) $\frac{65}{328}$ ____________

g) $4\frac{3}{7}$ ____________

h) $\frac{5}{4}$ ____________

2. Resolva as seguintes operações:

a) $\frac{3}{2}+\frac{7}{2}$ ____________

b) $\frac{5}{6}+\frac{8}{3}$ ____________

c) $\frac{3}{5}+\frac{2}{9}+\frac{3}{15}$ ____________

d) $\frac{4}{7}-\frac{2}{3}$ ____________

e) $2\frac{5}{8}+\frac{9}{15}-\frac{12}{3}$ ____________

PROCEDIMENTOS ÉTICOS

Conflito de interesses: nada a declarar. **Financiamento**: nada a declarar. R**evisão por pares**: Dupla revisão anónima por pares.