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Respostas emocionais na interação física entre usuários e produtos: EEG como alternativa metodológica - estudo de caso

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Resumo Métodos de Design dependem de instrumentos que avaliam as respostas emocionais como componentes da usabilidade das interfaces. Entre os instrumentos fisiológicos destaca-se a eletroencefalografia (EEG), a qual baseia-se em tecnologias computacionais e na neurociência. Entretanto a aplicação do EEG nos processos de interação física entre usuários e produtos é incipiente. O presente estudo de caso objetivou avaliar as respostas emocionais na interação física entre usuários e produtos, visando verificar se o design dos produtos influenciam os valores (Alpha μV^2) e as valências emocionais. De caráter experimental, aplicado e com amostra de conveniência (n=2), o EEG foi empregado durante a interação física com quatro produtos de uso cotidiano; e os dados analisados a partir de princípios da "assimetria cortical". Os resultados apontam que não houve diferença significativa ($p>0,05$) entre Left Alpha μV^2 e Right Alpha μV^2, para nenhum dos produtos, apesar de diferenças maiores que 10%, tanto na análise geral para cada produto, como para cada uma das etapas de interação, impactando na valência alcançada. O EEG demonstrou-se viável na avaliação da valência, em atividades reais.

Palavras-chave Design de Produto, Resposta Emocional; Eletroencefalografia; Valencia.

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Emotional responses in physical interaction between users and products: EEG as a methodological alternative - case study

Abstract *Design methods depend on instruments that evaluate emotional responses as components of interface usability. Among physiological instruments, electroencephalography (EEG) stands out based on computer technology and neuroscience. However, the application of EEG in physical interaction processes between users and products is incipient. The present case study aimed to evaluate emotional responses in the physical interaction between users and products, aiming to verify whether product design influences values (Alpha μV²) and emotional valences. Experimental in character, applied and with a convenience sample (n=2), the EEG was employed during physical interaction with four everyday products, and the data were analyzed based on principles of "cortical asymmetry." The results indicate that there was no significant difference (p>0.05) between the Left Alpha μV² and Right Alpha μV² for any of the products, despite differences greater than 10%, both in the overall analysis for each product and for each of the interaction stages, impacting the achieved valence. The EEG proved to be viable in assessing valence in real activities.*

Keywords *Product Design; Emotional Response; Electroencephalography; Valence.*

Respuestas emocionales en la interacción física entre usuarios y productos: EEG como alternativa metodológica - estudio de caso

Resumen *Los métodos de diseño dependen de instrumentos que evalúan las respuestas emocionales como componentes de la usabilidad de la interfaz. Entre los instrumentos fisiológicos está la electroencefalografía (EEG), que se basa en tecnologías informáticas y neurociencias. Sin embargo, la aplicación de la EEG a los procesos de interacción física entre usuarios y productos está aún en sus primeras fases. El objetivo de este estudio de caso fue evaluar las respuestas emocionales con EEG en la interacción física entre usuarios y productos, para ver si el diseño del producto influye en los valores (Alfa μV²) y las valencias emocionales. Mediante procedimientos experimentales y aplicados, y con una muestra de conveniencia (n=2), se utilizó EEG durante la interacción física con cuatro productos cotidianos, y los datos se analizaron utilizando los principios de la «asimetría cortical». Los resultados muestran que no hubo diferencias significativas (p>0,05) entre el μV² Alfa izquierdo y el μV² Alfa derecho para ninguno de los productos, a pesar de las diferencias de más del 10%, tanto en el análisis general para cada producto como para cada una de las fases de interacción, que repercutieron en la valencia alcanzada. El EEG demostró ser viable para evaluar la valencia en actividades reales.*

Palabras clave *Diseño de Productos; Respuesta Emocional; Electroencefalografía; Valencia.*

Introduction

Emotions constitute one of the essential qualities of human existence, and can be characterized as an amalgamation of the complexity of life experience and cognitive processes. Since Darwin (2009), through Scherer and Ekman (1984), Damásio (2012, 2018 and 2022), and other important scholars in the field, understanding human emotions has been a fertile field for new paths in scientific and applied research. With advances in new computer technologies and neuroscience, it has become possible to develop systems capable of recognizing and interpreting emotional expressions, enabling the creation of research protocols that capture different emotional states of individuals (Gkintoni et al., 2025), even making it possible to monitor emotions related to the use of products with different interfaces (designs).

According to Zhang, Fort and Giménez Mateu (2024), among the numerous protocols that evaluate human emotions, electroencephalography (EEG) stands out, which is characterized as a non-invasive technique for evaluating the brain's electrical fields using electrodes fixed to the scalp, and which record voltage potentials resulting from the flow of current within and around neurons in the cortex, propagating the transmission of nerve impulses (Biasiucci; Franceschiello and Murray, 2019). Its wide application in clinical and/or laboratory environments is due to characteristics such as good temporal resolution, ease of use, portability and affordable cost (compared to magnetic resonance imaging or computed tomography), and can be considered a robust emotion recognition technique (Li et al., 2022; Houssein, Hammad and Ali, 2022). On the other hand, there are still challenges related to its application in the evaluation of interactions between users and everyday products, as well as the identification of opportunities associated with emotion recognition, which requires a critical examination of its applicability.

The application of EEG in the evaluation of the interaction between users and information systems (computing) has been explored (Frey et al., 2014; Erat et al., 2024; Choi et al., 2024). On the other hand, there is still an incipient approach regarding the use of EEG in the evaluation of the interaction between users and products, a condition addressed in the studies by Kim, Chung and Kim (2022) and Soroush and Zeng (2024). Among the few experimental (applied) studies that place product design as an independent variable, the following stand out: Yilmaz et al., (2014), with shoe design; Guo et al., (2016), with smartphone case design; Guo et al. (2019), with table lamp design; and Zhu et al., (2022), with car dashboard design. However, in all these cases, the user-product interaction was strictly through the visual channel, having occurred from an image of the product, usually projected on a computer screen. Among the studies that effectively used a physical object and, therefore, a possibility of tactile interaction, the following stand out: Moon et al. (2019), with car design; and Sugiono et al. (2021) with computer mouse design, thus characterizing a gap in protocols that evaluate a physical (functional) activity with a product.

The present study aimed to evaluate emotional responses using EEG during user-product interactions in a real activity, aiming to determine whether product design influences EEG values (Alpha μV^2) and, consequently, emotional valences. Because it is a case study, a descriptive approach was chosen, which has a more significant impact on user-product interaction assessment methodologies.

Material and Methods

Study Characteristics and Ethical Aspects

The present study presents exploratory and descriptive characteristics with a cross-sectional, experimental, and applied approach. The methodological procedures followed the ethical precepts of "Resolution No. 510-2016" (CONEP/MS, 2016) and were approved by the CEP (CAAE 80331424.3.0000.5663). The Free and Informed Consent Form (FICF) was applied, informing the objectives and characteristics of the study, the risks and free will to participate. The independent variables were characterized by lemon squeezer designs (Figure 1) and five stages of interaction (View, Start, Step 1, Step 2 and Final), and the dependent variables were characterized by the result of alpha power (Alpha μV^2) and consequent valence (positive or negative).

Sampling

Considering being a case study, the sampling procedure adopted was of the intentional non-probabilistic type (Palinkas et al., 2015). Subsequently, three important criteria were adopted to define such procedures and, consequently, identify the participants: 1. be an adult and have full cognitive capacity; 2. have a thin and/or non-thick scalp since thick or voluminous hair may be associated with systematic differences in the quality and amplitude of the EEG signal (Lees et al., 2024); 3. not have training in the area of applied social sciences, especially design, architecture, arts or communication, ensuring that the participants' prior expectations regarding products with recognized symbolic value did not interfere with their perception during the interaction of using them (Lanutti and Paschoarelli, 2015).

Therefore, two (02) young adult individuals were selected and participated: P1 (20 years old), has short, thin hair and a background in civil engineering; P2 (27 years old), has short, thin hair and a background in computing.

Study Object

Four different citrus fruit squeezers were evaluated (Figure 1), since they are objects of daily and habitual use in the local culture whose handling requires minimal biomechanical efforts and whose morphological constitution can be presented with different recognized esthetic and symbolic values.

Two of these products were acquired exclusively through digital means and the import process (Juicer 1 - Figure 1-1; and Juicer 3 - Figure 1-3), with a recognized increased monetary and symbolic value. The other two juicers are commonly found in local stores (Juicer 2 - Figure 1-2; and Juicer 4 - Figure 1-4) and, therefore, have low recognized monetary and symbolic value.

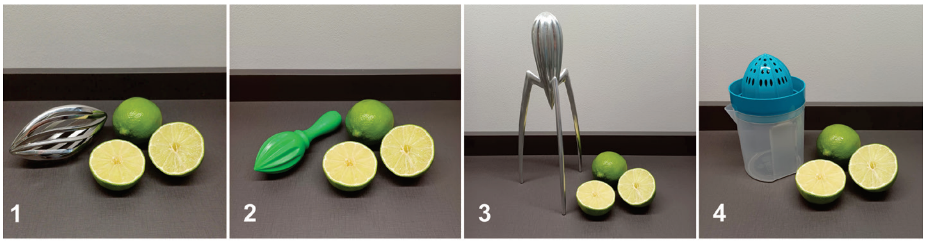


Figure 1. Citrus fruit juicers and their respective fruits (for dimensional understanding). 1 - "My squeeze" juicer created by designer Roland Kreiter, produced by Alessi in stainless steel, hollow body and without handle; 2 - "lemon squeezer" produced by Punto Cocina in plastic material, solid body and with handle; 3 - "Juice Salif" squeezer created by designer Philip Stark, produced by Alessi in stainless steel and aluminum, solid body and iconic design; and 4 - "Fit portable juicer" produced by Nitron in plastic material, hollow body and fluted cone with holes.

Source: Prepared by the authors, 2025.

Data Collection Procedures

All procedures were carried out in the Experiment Room of the Ergonomics and Interfaces Laboratory of Unesp, maintaining the standardization of air conditioning based on the following standards: NBR ISO/CIE 8995-1 (lighting), NBR 16401-2 (room temperature) and NBR 10152 (noise control), and a counter (sink) was used as the base of the activities. Recruitment followed the individual reception of each participant, with clarification of the purpose and procedures of the study, identification registration and application of the FICF (Free and Informed Consent Form). Preparation procedures included placing the cap with sensors as recommended by the EEG equipment supplier (Figure 2-A) and inserting conductive clinical gel (Figure 2-B), with the participant maintaining a sitting posture (Figure 2-C). To perform the activity, the participant remained in an upright posture facing the bench (Figure 2-D). The electrical signal quality parameters were verified in the sequence, and the participant was instructed to keep their eyes open following the assumptions of Yilmaz et al., (2024), and avoid sudden rotational movements of the trunk and neck, focusing visual attention on the activity. The participant was not informed about which products he would interact with.

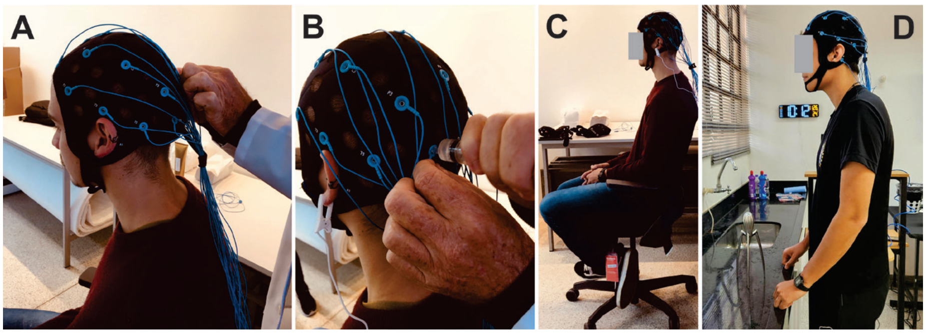


Figure 2. Preparation procedures with placement of the cap and sensors (A), insertion of conductive clinical gel in each of the sensors (B) and maintenance of the participant in a sitting posture (C). To carry out the activities, the participant maintained a standing posture (D), in front of the activity bench and was instructed not to make sudden movements of neck rotation, focusing visual attention on the activity.

Source: Prepared by the authors, 2025.

The interaction (Figure 3) was repeated with each of the four study objects (Figure 3-1, 3-2, 3-3 and 3-4), which were presented in a randomized sequence. The activity itself consisted of three distinct stages of interaction: First - presentation of the object of study (citrus juicer) and the already cut fruit (lemon), a situation in which the participant performed the visual interaction (View of interaction stage); Second - beginning of the tactile interaction stage (Start, Step 1 and Step 2 interaction stages), in which the participant should perform the task of squeezing the fruit and obtaining the juice; and Third - completion of the activity (Final interaction stage). At the end, the participant was asked to sit down to remove the sensors and was dismissed from the experiment.

Figure 3. Frontal view of the interaction activity (use) with juicer 1 (1); with juicer 2 (2); with juicer 3 (3) and juicer 4 (4).
Source: Prepared by the authors, 2025.

Data Analisys Procedures

The EEG data analysis procedure was based on the principle of "cortical asymmetry", advocated by Harmon-Jones (2003), Alves, Aznar-Casanova and Fukusima (2009), Berkman and Lieberman (2009), and Harmon-Jones, Gable and Peterson (2010), which refers to the difference in brain activity or morphology between the right and left hemispheres. In fact, this principle explains the relationship between this difference and emotional processing, suggesting that the frontal region of the left hemisphere focuses on processing positive stimuli and behaviors, while the frontal region of the right hemisphere focuses on processing negative stimuli and behaviors (Davidson, 1999; Alves, Fukusima e Aznar-Casanova, 2008; Barros et al., 2022).

In applied form, this procedure calculates the difference in alpha power (Alpha μV^2) between the left (FP1, F3 and F7) and right (FP2, F4 and F8) frontal electrodes. The presence of lower alpha power in the left electrodes, than in the right ones, suggests greater activity in the left region, providing a positive activation stimulus; and the presence of higher alpha power in the left electrodes, than in the right ones, suggests greater activity in the right frontal region, providing a negative activation stimulus.

Davidson (1999) demonstrated that the prefrontal cortex is a region of high affective asymmetry. The anterior region of the left hemisphere is associated with approach behaviors and positive affect, while the anterior part of the right hemisphere is associated with withdrawal behaviors and negative affect. A study developed by Jones and Fox (1992) found greater left hemisphere activation during positive affect and greater right hemisphere activation during negative affect. The prefrontal cortex mediates the control of high-level cognitive functions and is associated with the regulation of many aspects of the affective system. It has been proposed that the prefrontal cortex stores representations of goals and the means to achieve them, working in an emotion-based decision-making system (Davidson, 2008).

Associated with this principle, some authors have assumed that investigation of cerebral asymmetry should concentrate on small brain regions rather than entire hemispheres. For example, Wager et al., (2003) suggest that the entire hemisphere is too general a unit of measurement to be described by neuroimaging data. Therefore, a more refined level of anatomical specificity is necessary. These conclusions are based on a meta-analysis of 65 neuroimaging studies investigating cerebral asymmetry. They found no differences between the cerebral hemispheres when each hemisphere was analyzed as a whole. However, when smaller brain structures were compared, a more complex pattern of cerebral asymmetry emerged from the data.

For the present data analysis, the mean and standard deviation (SD) of alpha power (Alpha μV^2 - dependent variables, n=30) were calculated for each region of the frontal cortex: left FP1, F3 and F7 and right FP2, F4 and F8 for each of the products analyzed (independent variables). In order to verify the occurrence of significant differences between the independent variables, the JASP 019.3.0 software was employed, applying the Shapiro-Wilk test, aiming to verify compliance with the normality assumptions (Mishra et al., 2019). Considering that none of the sample groups met this assumption ($p \leq 0.05$), the Wilcoxon test ($p \leq 0.05$) was applied to compare the (paired) results of the independent variables, totaling 16 comparisons: four for each "left" and "right" pair; and 12 for cross-comparisons.

Considering that no statistically significant differences ($p > 0.05$) were found between the Left Alpha μV^2 and Right Alpha μV^2 for any of the products analyzed (independent variables), in the present study, it was decided to consider the general difference between the means, expressed as a percentage (%). As a result, when this general difference between the averages exceeded 10%, the valence result was considered expressive. The mean and standard deviation (SD) of alpha power (Alpha μV^2 - dependent variables, n=6) were also obtained for each region of the frontal cortex: left FP1, F3 and F7, and right FP2, F4 and F8 for each of the products analyzed (independent variables), considering the different stages of interaction (independent variable): View - the two-second interval from the participant's viewing of the product and fruit; Start - the two-second interval from the participant's beginning of tactile interaction with the product and fruit (the actual activity itself); Step 1 - the two-second interval after the first 10 seconds of the start of the tactile interaction; Step 2 - the two-second interval within the last ten seconds before the completion of the activity; Final - the interval of the first two seconds after the completion of the activity. These results were also analyzed considering the general difference between the averages, expressed as a percentage (%), with the valence result being considered expressive when the difference exceeded 10%.

Results

The results (Figure 4) present the four products (1, 2, 3 and 4) evaluated (independent variables); the Left Alpha μV^2 results (mean and SD); the L x R comparison, with the difference between them (in percentage); the Right Alpha μV^2 (mean and SD); and the valence (positive, negative or neutral - dependent variables) of each of the products evaluated. Note that for Product 1, the Right Alpha μV^2 (44.50 ± 36.15) was 11.25% greater than the Left Alpha μV^2 (40.00 ± 26.03), thus determining that the prevailing valence in the interaction with this product was positive. For Product 2, the Left Alpha μV^2 (46.07 ± 37.87) was 14.11% greater than the Right Alpha μV^2 (40.37 ± 31.83), thus determining that the prevailing valence was negative. On the other hand, for Product 3, the Right Alpha μV^2 (43.59 ± 21.53) was 4.25% greater than the Left Alpha μV^2 (41.82 ± 23.36); and for Product 4, the Left Alpha μV^2 (29.34 ± 19.54) was 7.79% greater than the Right Alpha μV^2 (27.22 ± 19.59), thus determining that for both products the prevailing valence was considered neutral.

The statistical analysis did not indicate a statistically significant difference ($p>0.05$) between the Left Alpha μV^2 and Right Alpha μV^2 for any of the products analyzed. A statistically significant difference ($p \le 0.05$) was observed between the results of the Right Alpha μV^2 when comparing Product 1 and Product 4; and between Product 3 and Product 4, with Product 4 presenting a lower average, which can be interpreted as resulting in lower brain activity in the frontal region of the right hemisphere.

Figure 5 presents the four evaluated products and their respective stages of interaction use (View, Start, Step 1, Step 2, and Final - independent variables); the Left Alpha μV^2 results (mean and SD); the L x R comparison, with the difference between them (in percentage); the Right Alpha μV^2 (mean and SD); and the valence (positive, negative or neutral - dependent variables) of each stage of interaction of use.

In this case, it is noted that for Product 1, in the first stage (View), the Left Alpha μV^2 (60.13 ± 13.52) was 12.87% greater than the Right Alpha μV^2 (53.27 ± 39.41), thus determining that the prevailing valence was negative.

In the next stage (Start), the Right Alpha μV² (37.77 ± 17.32) was 6.99% greater than the Left Alpha μV² (35.30 ± 20.71), characterizing a neutral valence. From the following stages (Step 1, Step 2 and Final), the Right Alpha μV² (19.17 ±7.74; 38.48 ±32.14 and 73.80 ±51.48, respectively) was significantly greater (> 10%) than the Left Alpha μV² (16.45 ±12.31; 31.53 ±15.12 and 56.58 ±36.64, respectively), determining that the prevailing valence in these stages was positive.

In the analysis of Product 2, it is observed that in the first stage (View) the Right Alpha μV² (31.01 ±7.51) was 12.11% greater than the Left Alpha μV² (27.65 ±5.22), thus determining that the prevailing valence was positive. In the next stage (Start), the Left Alpha μV² (41.18 ±26.46) was 4.43% greater than the Right Alpha μV² (39.43 ±17.29), characterizing a neutral valence. In the two following stages (Step 1 and Step 2), the Left Alpha μV² (30.38 ±11.04 and 39.64 ±15.06, respectively) was significantly greater (> 10%) than the Right Alpha μV² (21.41 ±13.72 and 22.22 ±8.39, respectively), determining that the prevailing valence in these stages was negative. Finally, in the Final stage, the Left Alpha μV² (91.50 ±63.11) was 4.23% greater than the Right Alpha μV² (87.78 ±40.41), characterizing a neutral valence.

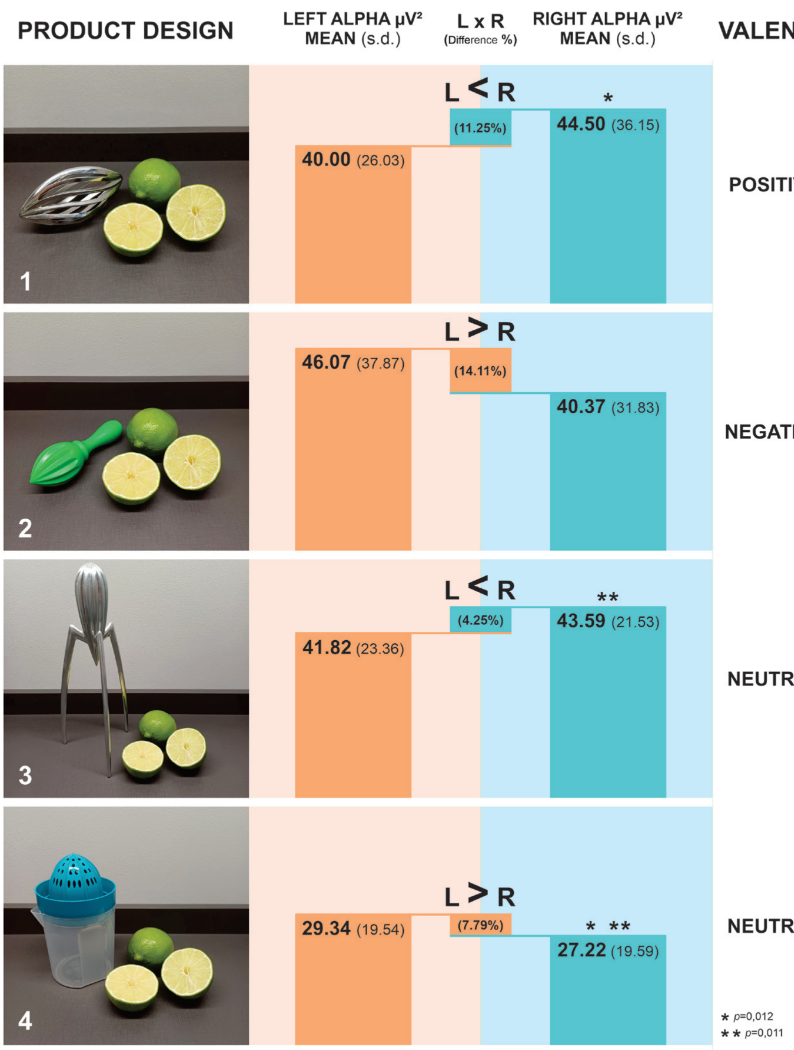
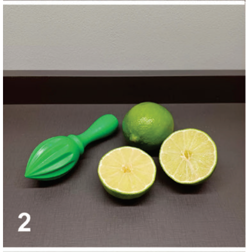


Figure 4. The first column shows the products (1, 2, 3, and 4) evaluated (independent variables); the remaining columns show the Left Alpha μV² (mean and SD); the result of the L x R comparison with the difference between them (in percentage); the Right Alpha μV² (mean and SD); and the valence (positive or negative) of each of the products evaluated (dependent variables). The p-value (Wilcoxon) is also presented in the event of a significant difference (p≤0.05).

Source: Prepared by the authors, 2025.

Figure 5. The first column shows the products (1, 2, 3, and 4) evaluated (independent variables); the remaining columns show the Left Alpha μV² (mean and SD); the result of the L x R comparison with the difference between them (in percentage); the Right Alpha μV² (mean and SD); and the valence (positive or negative) of each of the products evaluated (dependent variables). The p-value (Wilcoxon) is also presented in the event of a significant difference (p≤0.05).

Source: Prepared by the authors, 2025.

PRODUCT DESIGN	STAGE	LEFT ALPHA μV² MEAN (s.d.)	L x R (Difference)	RIGHT ALPHA μV² MEAN (s.d.)	VALENCE
 1	View	60.13 (13.52)	L > R (12.87%)	53.27 (39.41)	NEGATIVE
	Start	35.30 (20.71)	L < R (6.99%)	37.77 (17.32)	NEUTRAL
	Step 1	16.45 (12.31)	L < R (16.53%)	19.17 (7.44)	POSITIVE
	Step 2	31.53 (15.12)	L < R (22.04%)	38.48 (32.14)	POSITIVE
	Final	56.58 (36.64)	L < R (30.43%)	73.80 (51.48)	POSITIVE
 2	View	27.65 (5.22)	L < R (12.11%)	31.01 (7.51)	POSITIVE
	Start	41.18 (26.46)	L > R (4.43%)	39.43 (17.29)	NEUTRAL
	Step 1	30.38 (11.04)	L > R (56.21%)	21.41 (13.72)	NEGATIVE
	Step 2	39.64 (15.06)	L > R (78.39%)	22.22 (8.39)	NEGATIVE
	Final	91.50 (63.11)	L > R (4.23%)	87.78 (40.41)	NEUTRAL
 3	View	69.98 (17.62)	L > R (40.46%)	49.82 (28.00)	NEGATIVE
	Start	42.33 (23.46)	L < R (15.21%)	48.77 (23.31)	POSITIVE
	Step 1	45.81 (16.61)	L < R (10.15%)	50.46 (16.92)	POSITIVE
	Step 2	16.81 (8.14)	L < R (99.94%)	33.61 (24.32)	POSITIVE
	Final	34.16 (13.02)	L < R (3.36%)	35.31 (12.10)	NEUTRAL
 4	View	20.78 (3.17)	L > R (5.48%)	19.87 (3.08)	NEUTRAL
	Start	20.52 (7.42)	L > R (31.37%)	15.62 (7.84)	NEGATIVE
	Step 1	19.96 (11.74)	L > R (46.76%)	13.60 (9.62)	NEGATIVE
	Step 2	52.22 (24.59)	L > R (1.95%)	51.22 (19.71)	NEUTRAL
	Final	33.23 (21.77)	L < R (7.73%)	35.80 (21.08)	NEUTRAL

In the analysis of Product 3, in the first stage (View), the Left Alpha μV² (mean 69.98 ±17.62) was 40.46% greater than the Right Alpha μV² (mean 49.82 ±28.00), thus determining that the prevailing valence was negative. In the following three stages (Start, Step 1 and Step 2), the Right Alpha μV² (mean 48.77 ±23.71; 50.46 ±16.92; and 33.61 ±24.32, respectively) was significantly greater (> 10%) than the Left Alpha μV² (mean 43.33 ±23.46; 45.81 ±16.61; and 16.81 ±8.14, respectively), characterizing a positive valence. In the Final stage, the Right Alpha μV² (mean 35.31 ±12.10) was only 3.36% greater than the Left Alpha μV² (mean 34.16 ±13.02), determining that the prevailing valence in this stage was neutral.

The results related to Product 4 indicate that in the first stage (View) the Left Alpha μV² (20.78 ±3.17) was 5.48% greater than the Right Alpha μV² (19.87 ±3.08), determining that the valence was neutral. In the two following stages (Start and Step 1), the Left Alpha μV² (20.52 ±7.42 and 19.96 ±11.74, respectively) was significantly higher (> 10%) when compared to the Right Alpha μV² (15.62 ±7.84 and 13.60 ±9.62, respectively), determining that the prevailing valence in these stages was negative. And in the last two stages (Step 2 and Final), the Left Alpha μV^2 (52.22 ±24.59 and 33.23 ±21.77, respectively) was higher, but considered not significant (< 10%) when compared to the Right Alpha μV^2 (51.22 ±19.71 and 35.80 ±21.08, respectively), determining that the prevailing valence in these stages was neutral.

Discussion

Understanding emotional responses in the interaction of using a product has become one of the greatest contributions to design methods in recent decades since they comprise one of the main factors contributing to knowledge about the importance of user experience in product design (Gada and Chudasama, 2024). The present study analyzed emotional responses based on electroencephalography (EEG) analysis in the interaction between users and products in a real activity. It also sought to verify whether product design and interaction stages (independent variables) influence EEG Alpha μV^2 values and emotional valences (dependent variables).

In general, it is observed that Product 1 and Product 2 presented a significant difference (>10%) between the Left Alpha μV^2 and Right Alpha μV^2. In fact, Product 1 influenced the occurrence of positive emotional responses, and this probably occurred because it is a product whose formal, functional, and material aspects provided a truly innovative experience for the study participants, perceived during the performance of a trivial activity (squeezing a lemon). Product 2 influenced the occurrence of negative emotional responses since its formal, material and finishing characteristics (matte texture and opaque, saturated color) associate it with a product that is not very innovative and has low social and symbolic value, contributing to a negative emotional response. For Yu and Wang (2022), emotion is inseparable from the human condition and affects normal human physiological activities and everyday life decisions. Therefore, the triviality of the activity (squeezing a lemon) does not seem to have contributed to any of the emotional responses found, but rather (and almost exclusively) the design of the products.

It is noteworthy that the formal, functional, and material characteristics of Product 1 are completely different from those of Product 2, which allows us to affirm that, in this case, the design influenced the valences and, therefore, the emotional response during the user interaction. This is probably the case related to the contradictory emotions described by Desmet (2002).

In the case of Product 3 and Product 4, the differences between Left Alpha μV^2 and Right Alpha μV^2 were less than 10% in both cases. Therefore, considering the variability of the results (in all analysis situations), the valences were considered neutral. In any case, when analyzing the results related to the interaction stages, it is observed that in Product 3, in three stages (Start, Step 1 and Step 2), there was a prevalence of positive valences; while in Product 4, in two stages (Start and Step 1), there was a prevalence of negative valences. In all other stages, and for both products, the predominant condition was neutral. In this sense, Product 3 probably influenced the occurrence of positive emotional responses, given its similar formal, functional, and material aspects to Product 1, providing an innovative user experience for participants. Product 4, on the other hand, may have influenced the occurrence of negative emotional responses, as observed with Product 2.

From a theoretical point of view, Product 3 is considered a product with iconic design (Russo and Moraes, 2003). According to Lees-Maffei (2014), these products are those that stand out for their esthetic aspect, in which form surpasses function. This approach presents the design object as an artistic object simultaneously. The most striking feature that distinguishes Product 3 from its counterparts (e.g., Product 4) and makes it iconic is its sculptural esthetic.

Lees-Maffei (2014) also states that juicers like Product 4 are a reinterpretation of conventional citrus juicers which are often seen as neglected and prototypical kitchen appliances, where the boundaries between the application of design principles and visual arts are blurred. According to Heskett (2002), Product 4 focuses too much on esthetics to the detriment of its pragmatic function, being considered more like a sculpture for the food preparation environment.

It should not be forgotten that, in relation to the evaluation of emotional responses using EEG during user-product interaction, the study by Nascimento (2024) stands out in Brazil, providing additional contributions.

Conclusion

The present study indicates that product design can influence (positively or negatively) users' emotional responses. It also contributed to methods for assessing user-product interaction since the physiological EEG instrument proved to be a robust alternative for this function.

Despite this robustness, EEG can only be considered efficient for this purpose when its protocol considers other instruments and evaluation parameters, including physiological measurements (e.g., microexpressions, or facial expressions), or perceptive measurements (e.g., self-report). Furthermore, other important considerations should be taken into account, not only regarding the data collection protocol but also data analysis. Integration with other variable control instruments can contribute to more significant results.

Finally, the recognition of human emotion during interaction with everyday products appears to be an essential approach that, together with other artificial intelligence tools, and artificial intelligence itself, can enable the development of other fields of research and innovation in product design.

Artificial Intelligence (AI) Use Policy

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation of this manuscript. All content was conceived, written, and critically reviewed by the authors, who accept full responsibility for the accuracy, integrity, and originality of the work, as well as for the information, analyses, and conclusions presented.

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