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Semantic Kansei Engineering Approach for Game Controllers and Design Improvement

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Abstract: The entertainment industry undergoes constant changes, and video games, along with the ways people enjoy them, evolve dynamically. In this context, there arises a need to innovate in areas such as user–game interaction and the design of conventional controllers to keep up with these transformations. This study has found that the design requirements of the external geometry of video game controllers significantly impact users' purchasing decisions, who often rely on their sensations and emotions. The primary aim of this research has been to demonstrate that it is possible to develop a specific methodology to establish design guidelines that evaluate geometry and ergonomic aspects, considering users' emotional needs. To achieve this goal, the Kansei methodology has been employed, an engineering discipline that focuses on product design based on emotional interaction and user sensations when using them. Through advanced statistical techniques such as principal component analysis and linear regression, the set of observations has been reduced and a robust predictive model has been developed. Following this methodological approach, surveys and field studies have been conducted, thus differentiating the project from a conventional engineering approach in various stages. Special attention has been paid to the tactile part of the controller, especially its casing. After thorough analysis, the redesigned casing, incorporating improvements derived from statistical analyses, has been compared to existing market models. The results obtained show a significant improvement compared to existing market models, particularly highlighting enhancements in functional characteristics and ergonomic design, enabling comfortable use for individuals with different hand sizes and preventing the grip surface from being slippery. In summary, this work supports the effectiveness of the Kansei methodology as an approach to adapting product design to users' perceptions and emotional needs.

Keywords: games control design; Kansei; sensations; haptics; principal component analysis; linear regression

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1. Introduction

In a world in which technology dominates most areas of human life, there is an ever-evolving world of entertainment, either with multimedia streaming services that boomed during the pandemic or other digital content like music or video games. In this context, there is a constant struggle between the big video game companies to innovate how their games are played [1].

Product design is an innovative activity that aims to develop a perfect product to meet users' emotional needs [2]. End users are the ideal candidates to evaluate the product, and their opinions are essential for the discipline of industrial design to include in its work process. Traditionally, creativity in industrial design came fundamentally from the designer's experience [3]. However, this model has become outdated given that the

appearance of products is one of the main purchasing factors for end users [4], which forces designers to be more attentive to the emotions and sensations of end users.

Products can provoke multiple simultaneous emotions in users, some of which may even be contradictory. Coupled with each designer's personal and professional differences, this can trigger various emotions [5]. Therefore, guidance on the best typology or the one most used by other professionals with more experience is required if this helps develop the work with greater guarantees of success [6].

Specifically, the external design requirements of a product represent a typical perceptual demand [7], noting that when the basic functional requirements are met, the additional satisfaction of perceptual needs can significantly increase the purchasing intentions of users. In our case study, the design requirements of the external geometry of video game controllers greatly influence users' purchasing decisions through their sensations and emotions.

This study aims to prove that the proposed methodology is valid for obtaining concrete design specifications to evaluate the geometry and validate ergonomic aspects and appearance of the product under study. Product planners and designers must consider the unique perceptual needs of each user and translate them into concrete design features for product lines and market segmentation to increase consumer purchase interest [2,8].

If the video game industry is taken as a benchmark, there is little information on users' continued use of a product [9]. Most studies focus on specific games and do not reveal the correlation between the technical aspects of the games, the importance of the hardware used, or the user experience [10]. If you focus on the hardware—as this paper intends—manufacturers tend to provide the user with controllers with better features that promote playability. Under this condition, the game control experience has been valued by gamers, which led to the addition of a joystick, even in games played on smartphones [11,12].

While gamers are passionate about their controllers and gaming environments, independent empirical evaluations quantifying and comparing human performance with game controllers are rare [13].

Some authors have identified in their works that product comfort is related to the success and sales of video game manufacturing companies, relating comfort to the companies' sales patterns [14]. This work has helped us set the basis for our study and identify the accessibility control features of all the controller's functionalities.

Kansei Engineering refers to a concept in psychology concerning the integration of the different senses of consumers (vision, hearing, smell, and touch, among others) and the cognition caused by the size, colour, performance, price, and other product factors, i.e., product attributes [15]. This method can be applied to distinct areas of design [6], such as the design of physical products [16], the automobile industry [17], or services [18,19]. This method's basic principles are based on identifying product properties and the correlation between these properties and the design features. This method has three fundamental points: how to understand the Kansei consumer accurately, how to reflect and translate this understanding into product design, and how to create a system and organisation for Kansei-oriented design [20]. One of the first industries to successfully incorporate the Kansei methodology into their design processes was the automotive sector [21], but its field of application rapidly extended to electronic devices [22], interactive games [23], and even services [24].

Mathematical models, such as neural networks, are used to process these variables [25], but statistical techniques, such as principal component analysis (PCA), are also used to reduce the set of variables studied. This tool has been used to evaluate scores on the semantic differential [26] or to study the emotional responses associated with the shape of products [27]. Another statistical technique used in Kansei Engineering is regression models, such as ordinal logistic regression, to analyse the joint analysis results applied to mobile phone design [28]. However, using both statistical methodologies to study emotional responses to product design is commonplace. Several studies have used PCA and LR models for designers' and consumers' emotions [29,30].

In our case, the design variables of video game controllers were determined using a mathematical model divided into two processes: PCA to reduce the number of variables and LR to predict the effects that minor changes in the coordinates of the video game controllers have on the Kansei adjectives [31] and, consequently, on the factors obtained through PCA. Within the proposed model, words representative of Kansei Engineering evaluated the characteristics of shape and geometry in a survey.

Some minor goals must be set to reach the main objective. As Kansei Engineering is strongly based on market status and users' subjective opinions, one goal to be set is to study the target audience. Another objective related to the results of this research is ergonomics. The shape and size of people's hands must also be considered in this part of the project. Besides, there is a series of more specific objectives, such as documenting users with minimal experience in video games, designing the components considering the manufacturing process, extending the use of Kansei Engineering to the field of video games, redesigning the controller based on this study, and finally, comparing the classic design with the design based on the Kansei method.

These objectives will be developed based on Kansei Engineering, which will facilitate the procedure in some phases of this project. For example, when documenting users, people with minimal experience in video games will be needed. The international standards that regulate this area will also be considered. The scope of this project will be the application of Kansei Engineering in the video game controller market to demonstrate its usefulness to companies. In this sense, the methodology will be applied to the design of the outer shell of the controller, but ergonomics will be considered for the grips. The study population will be surveyed on the Kansei words that will be developed later but will be in line with trends, ergonomics, texture, and component strength. At the end of this study, the data will be applied to a previously created classic design to compare and contrast the characteristics of this methodology with those of the usual methods.

The following sections explain the development of this study. Section 2 briefly studies the market and the main components of video game controllers, with the final objective of understanding the geometry and importance of the controller's ergonomics. Section 3 describes the methodology used for the innovative controller design through Kansei Engineering with a mathematical model based on PCA and a subsequent linear regression model. The results obtained are shown and analysed in Section 4. Finally, the conclusions of this study are set out in Section 6.

2. Theoretical Background

The main objective is to design a technical project for an innovative video game controller using Kansei Engineering or emotional design to study users' interactions and responses to the product's physical attributes [32], especially in terms of ergonomics. Kansei Engineering is an ergonomic technology that evaluates the many combinations offered from the customer's viewpoint, proving to be a valuable tool for the experienced designer [33]. Therefore, the aim is to validate an original design based on the traditional method, apply Kansei Engineering to check that users' emotional responses are effectively collected, and then redesign the video game controller, which should be an improvement compared to the classic design. The particular design, specifically projected to receive Kansei Engineering, can be seen in Figure 1.

This preliminary design stemmed from applying a traditional methodology that prioritised some features over others. The most prominent features of video game controllers, such as integrated or external storage, modularity coupled with independent controllers, and ergonomics, were prioritised. For integrated or external storage, there is a need for backup storage to store screenshots or game saves, enabling interactivity with other players or on other consoles of friends, family, or acquaintances.

Figure 1. Original video game controller.

Ergonomics is a fundamental aspect in the design of a controller since simple shapes are not enough; it must also be able to accommodate a wide range of hand sizes. Therefore, the shapes of the most ergonomic hand controllers and the hand percentiles of the population had to be studied to serve as references when designing the initial proposal [34].

Some studies have compared the grips of different controllers throughout the history of video games up to 2008 [35]. They show that the most popular grip is the two-handed one, with one thumb on each joystick enveloping the sides. Other joysticks share many similarities in their grips, which has been one of the main criteria when designing the initial alternative used in this study, based on a comparison of the shells of the main Nintendo (Nunchuk), Xbox, and PlayStation controllers (see Figure 2).

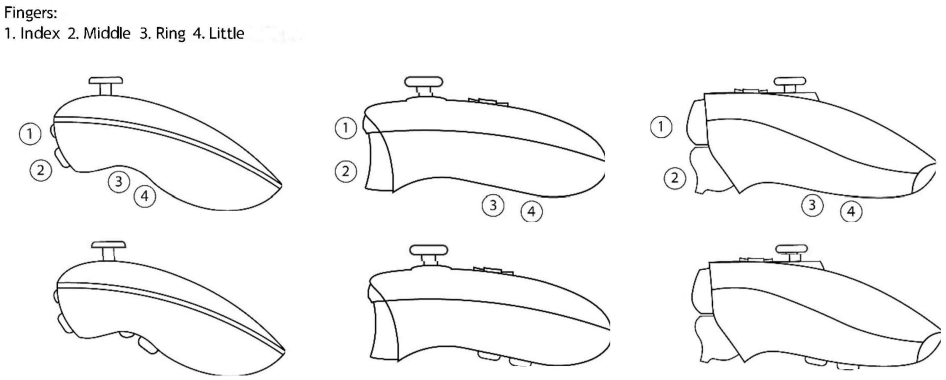


Figure 2. Comparison of Nintendo, Xbox, and PlayStation surfaces.

For a better understanding of a game controller, it must be broken down into essential parts (Figure 3). As with any other problem to be solved, a preliminary analysis must be carried out. The first thing you see is the front part, which is mainly made up of buttons and housing. Besides that, you have the rear triggers, joysticks, speakers, microphone, sensors, lights, and ports.

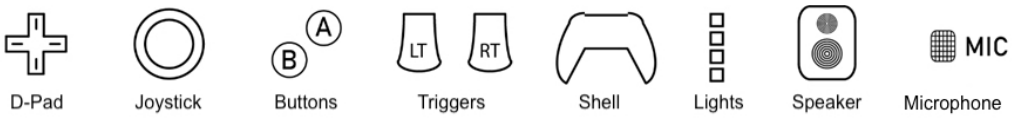


Figure 3. Controller components.

What changes from one controller to another is the use of the buttons and their distribution on the shell, which is the main difference between gaming companies. In addition, the control method is not necessarily button-based; however, in most cases, it is, or sensors are added. It is rarely controlled exclusively by gestures or movements since this is extremely complicated given the number of actions performed in a game.

In terms of in-game control, the relationships between the action–feedback cycle and its central role in gameplay are important aspects of game controller integration. The user must

have a sense of control that directly relates to their actions; this, in turn, works to reduce potential frustrations and enhances the user's participation in the game. Ultimately, the control of a game is the product of a well-designed interaction with game controllers [36].

Another limitation of the studies we have found is the limited consideration of the impact of controller aesthetics. Established controllers have the advantage of optimised ergonomics and refined aesthetics (colours, material textures) [36]. Researchers have demonstrated the relationships between product usability and product aesthetics [37].

The most standardised form in this field is the type of controller used, such as those for PlayStation or Xbox. Over the years, Nintendo has consistently innovated with each new generation of consoles, altering previous versions and introducing new gameplay and control methods. A prominent example is the Nintendo Wii, as illustrated in Figure 4. Despite higher error rates, the Wiimote became the preferred video game controller, with its advantages in increased throughput outweighing the decrease in accuracy.

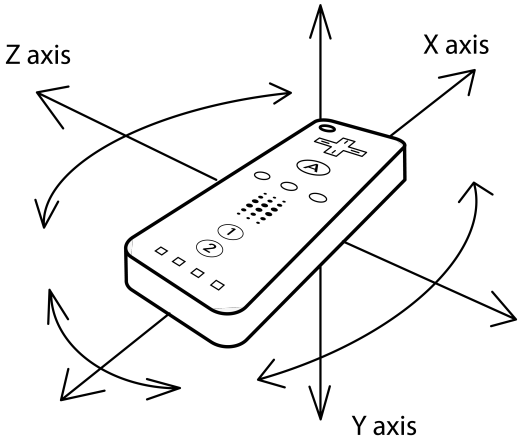


Figure 4. Wiimote axis system.

Another factor to consider is the market for this type of video game controller. Analysing the sales of the major video game companies in recent years highlights the importance of this market and how the sector has become one of the leading industries in the world. Some authors have documented the sales of the most popular consoles and video games worldwide [1].

Nintendo and Sony stand out as the leading companies in the video game sector, followed by Microsoft. Among these, the Japanese company is by far one of the longest-established in the console market. It began its path with the first PlayStation. The other companies have either disappeared or remained in the video game scene without manufacturing consoles, dedicating themselves exclusively to developing video games.

Sony's venture into controllers for desktop consoles began with DualDigital, the first controller for PlayStation consoles, as illustrated in Figure 5. It did not have an analogue function or joysticks but paved the way for the company's later products. In 1997, DualAnalog was launched, an evolution of this controller that included an analogue function, allowing three-dimensional control through the joysticks. Dualshock was finally released in 1997 and included a vibration motor. These details were also considered both in the initial design using the traditional method and in the development after applying Kansei Engineering. They were the main reason, along with the number of sales explained above, for selecting this type of controller in our study.

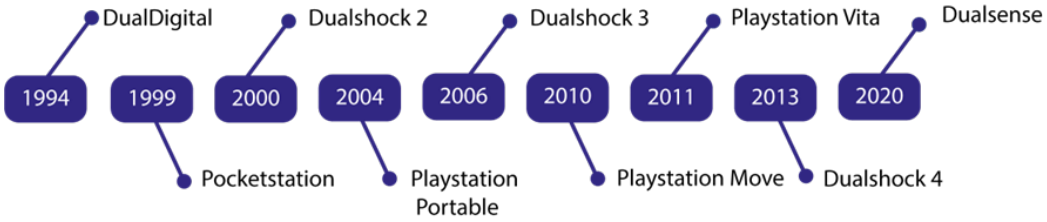


Figure 5. Sony chronology.

3. Materials and Methods

3.1. Background

The highest video game consumption is found among adults aged 18 to 44 years, making this group the target audience for this study. According to the Entertainment Software Association [38], 66 percent of the US population plays video games, with 36 percent of these players being between 18 and 34 years old—the age group with the highest concentration. This is followed by those under 18 years old at 24 percent, and those between 35 and 44 years old at 13 percent. Consequently, the selected age range encompasses 49 percent of video game consumers. Additionally, given the similarities in societal characteristics and organisational systems, these data can be extrapolated to the population in this study.

3.2. Design Specifications

In product design, it is necessary to consider a list of requirements that can be classified as desirable, intermediate, and critical. A desirable requirement, such as being visually attractive, adds value to the product but is not essential for its functionality. Intermediate requirements, such as resistance to impacts and deformations, friction and compression, having a good cost/quality ratio, or being compatible with other systems or consoles, are those that indirectly affect the operation of the product. Finally, critical requirements are the most important, as the product's performance is affected if they are not met; these requirements include having an ergonomic grip, a pleasant touch, rigidity, and compliance with current regulations.

In terms of ergonomics, the specification criteria were based on the values of anthropometric data of users, which offer a range of ideal dimensions for parts such as buttons, triggers, etc., for both the 5^{th} and 95^{th} percentile of users. The criteria taken into account in the design phase are listed below [39]:

- **Criterion 1**: The buttons must be sufficiently wide in diameter to accommodate the 95^{th} percentile of users. Reason for testing: If the buttons are too small, users with larger fingers will not be able to press them accurately.
- **Criterion 2**: The spacing between the buttons should be sufficient to allow individual pressing by the 95^{th} percentile of users. Reason for testing: If the buttons are spaced too closely together, users with larger fingers might accidentally press multiple buttons at once.
- **Criterion 3**: The maximum movement angle on the analogue sticks should be small enough to allow a full range of motion for the 5^{th} percentile of users. Reason for testing: If the maximum movement angle is too wide, users with smaller hands will not be able to fully extend the analogue sticks, limiting their ability to completely control the game.
- **Criterion 4**: The force needed to press the buttons or move the analogue sticks should be manageable for the 5^{th} percentile of users. Reason for testing: Users in the 5^{th} percentile might experience fatigue if buttons requiring more force are used for extended periods.
- **Criterion 5**: The visual cues and feedback provided by the device should allow the user to intuitively know how to use it as intended. Reason for testing: This ensures that the controller can be used correctly and intuitively, enhancing the overall user experience.

The methodology used in this project is based on Kansei Engineering for product design. Therefore, the controller should be ergonomic, durable, and intuitive.

3.3. Preparation of the Experiment

Experts in industrial design were consulted to select the most representative products. In this case study, the product space comprises 14 video game controllers, as shown in Figure 6, including the design proposed by the authors (no. 14), aimed at reducing the mental workload of survey participants. The focus was placed on shape characteristics, while information on the product samples' branding, texture, and colour was ignored.

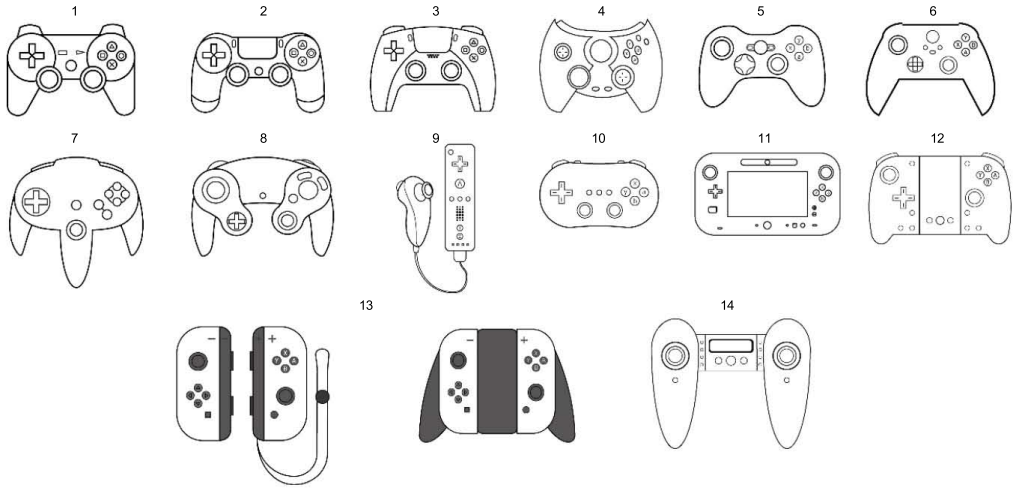


Figure 6. Video game controllers surveyed.

In product design research, single or paired adjectives can be used to describe consumers' emotional dimensions. Given that relationships such as relevance, dependence, redundancy, cause and effect, and similarity often exist between adjectives, paired adjectives are generally more suitable for capturing consumers' affective dimensions [40].

Websites, magazines, and directories facilitated the collection of Kansei words. These were obtained through open-ended questionnaires to cover the image space. The adjectives were selected by four experts in industrial design based on the experimental requirements and samples. Some researchers have explored the methodology of choosing adjective pairs in more depth, offering techniques for improving the selection of Kansei words and evaluation values on a more scientific and objective basis [41]. In our approach, we followed the traditional method, supported by professional profiles whose extensive experience enabled them to objectively identify the target pairs.

Adjectives related to the shape of the product were retained, and any words directly or indirectly related to colour, e.g., bright or colourful, were eliminated. As a result, 14 Kansei word pairs were selected as traditional-modern word pairs, as shown in Table 1.

Table 1. Kansei word pairs.

Traditional-modern	Straight-round	Serious-lively
Low class-high class	Warm-cold	Hardy-delicate
Ordinary-individualised	Simple-complex	Normal-creative
Mediocre-noble	Voluminous-reduced	Striking-discreet
Ergonomic-procrustean	Smooth-rough	

The schematisation or simplification of the product is another key factor in the design process, as it allows us to analyse the product from a more simplified perspective. The 3D feature lines of the main view were the primary form characteristic lines of the video game controller. These lines include two curves and different contour lines that define the video

game controller (Figure 7). Since the feature lines are approximate arcs, their definition was simplified to three feature points, as shown in Table 2 for the controller of Sample no. 1.

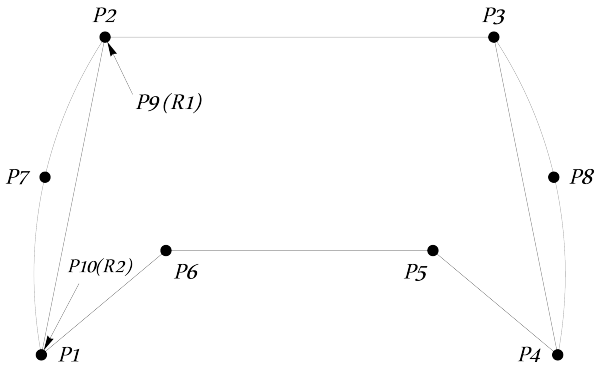


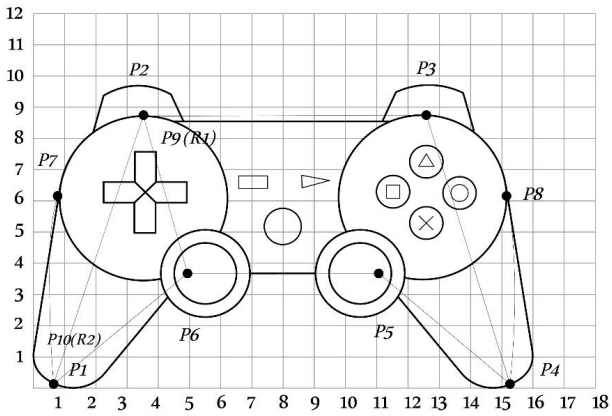
Figure 7. Coordinates of video game controllers.

In order to efficiently collect the data, a simple questionnaire was designed, the interface of which is shown in Figure 8. This design directly recorded the responses of each participant, allowing for simplified data analysis.

Figure 8. Sample survey for video game controller no. 1.

In this study, a 7-point Likert scale was utilised. A score of 7 indicates that the participant had a notably strong impression of the video game controller in relation to the adjective on the right-hand side, whereas a score of 1 signifies either a very weak impression of the adjective on the right-hand side or a very strong impression of the adjective on the left-hand side. The representative sample was created using Kansei words in the evaluation program (Table 1).

Table 2. Example of characteristic parameters.

Sample 1. Video Game Controller

Legend
Two curves from main view; points are defined as $p_{1x}, p_{1y}, p_{2x}, p_{2y}, p_{3x}, p_{3y}, p_{4x}, p_{4y}, p_{7x}, p_{7y}, p_{8x}, p_{8y}$
Different contour lines; points are defined as $p_{5x}, p_{5y}, p_{6x}, p_{6y}$
Radius on the contour $p_9 = R_1, p_{10} = R_2$

3.4. Experimental Stage

This paper discusses the design of a product that requires input from individuals with extensive experience in using it. Consequently, the population of interest was significantly narrowed. Specifically, 30 participants took part in this study, including 11 women and 19 men. Among them, 15 had a background in product design, 5 in engineering, and the rest were professionals from other fields. They were asked to evaluate images of various controllers after reviewing sample photos and to complete a survey.

Table 3 below shows the details and main characteristics of the group of subjects, specifying their experience in product design, the engineering field, or other activities.

Table 3. Main characteristics of the group of subjects surveyed.

Characteristics	**Mean/Total**	**Range (%)**	**Man**	**Woman**
Male/Female	-	-	19	11
Age (years)	35	23–42	-	-
Product Design Background	15	50%	7	8
Engineering background	5	17%	2	3
Other fields of activity	10	33%	6	4

3.5. Data Analysis Stage

In this study, a mathematical model for the Kansei methodology is proposed. This model applies two statistical techniques: principal component analysis (PCA) and linear regression (LR).

Our main objective is to find a model that enables the design of a more ergonomic video game controller compared to existing ones. To achieve this, we propose a linear regression model for the Kansei word pair ergonomic-procrustean, aiming to minimise its value. As we are also interested in a video game controller design that is modern and individualised, we incorporate these Kansei words into the linear model.

Figure 9 shows the correlation matrix of the Kansei word pairs. It presents correlations ranging from 0.4 to 0.6 between the Kansei pairs traditional-modern, straight-round, serious-lively, and low class-high class. Higher correlations are observed between the

Kansei pairs ordinary-individualised, simple-complex, normal-creative, and mediocre-noble. Conversely, a negative correlation is found with the Kansei pair striking-discreet. Additionally, the pairs voluminous-reduced and smooth-rough demonstrate correlations with the Kansei pair ergonomic-procrustean. Therefore, it is necessary to apply PCA.

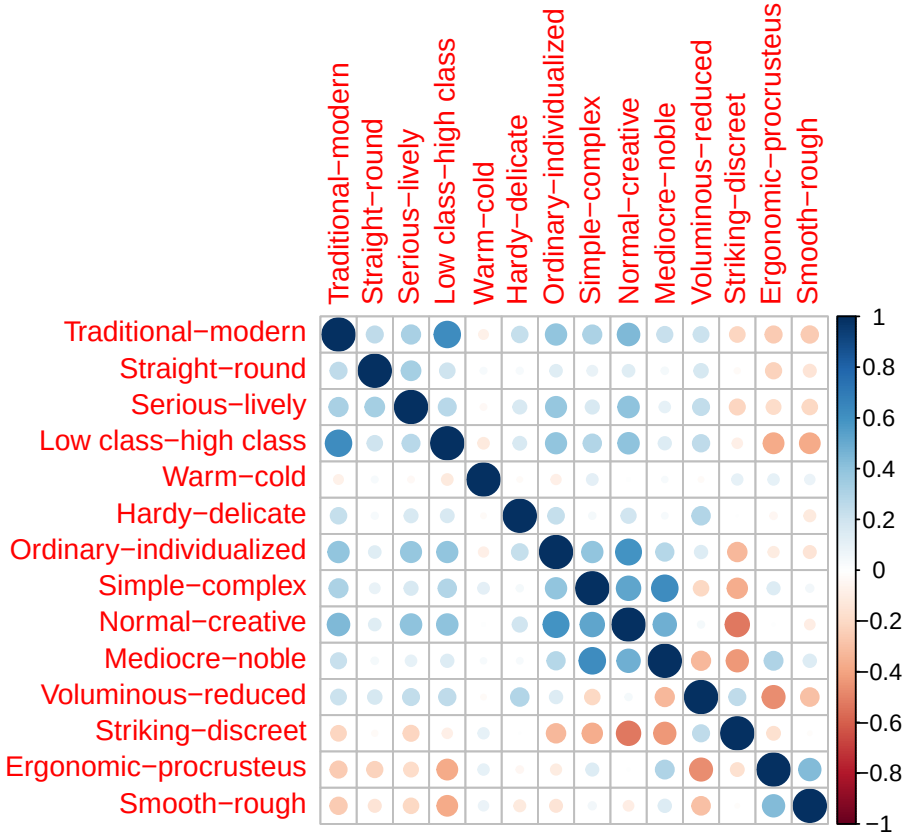


Figure 9. Correlation matrix of Kansei word pairs.

The PCA technique is used to reduce the number of variables to find a set of components that significantly represent the total variance. This methodology reduces the semantic space of pairs of Kansei words (Table 1) by creating a new set of variables, called factors, which capture the maximum amount of information. Specifically, we utilise this technique to identify factors that are then incorporated into a linear regression model created for the Kansei pairs traditional-modern and ordinary-individualised.

Additionally, a linear regression model is proposed to predict the effects of minor changes in the coordinates of video game controllers on the Kansei pairs traditional-modern and ordinary-individualised, and consequently, on the Kansei pair ergonomic-procrustean.

4. Results

Statistical analyses were conducted and graphs were generated using the R language. To perform the statistical analysis, we partitioned the dataset into two subsets, allocating 70% of the data for training the model and 30% for validation purposes.

In Table 4, we classify the different video game controllers surveyed according to their mean values for the Kansei words of interest. We can observe that our video game controller design ranks third for the Kansei pairs traditional-modern and ordinary-individualised but is positioned in eighth place in terms of ergonomics. Hence, we employed the Kansei methodology along with a mathematical model to improve these aspects.

Table 4. Classification of video game controllers surveyed. The designed video game controller is shown in bold.

Ranking	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th
Traditional-Modern	12	3	**14**	2	11	6	4	9	13	10	5	8	1	7
Ordinary-Individualised	12	11	**14**	9	3	2	8	7	6	10	4	13	1	5
Ergonomic-Procrustean	2	12	1	6	9	5	3	**14**	10	11	8	13	4	7

4.1. Linear Regression Model with Principal Component Analysis

Principal component analysis allowed three factors to be extracted from the relationships between the different Kansei words. These three factors explained 57.61% of the total variance. Using these three factors, we created linear regression models for the Kansei pairs tradional-modern and ordinary-individualised.

Figure 10 shows the behaviour of the observed values for the Kansei words of interest for each video game controller (light-blue violins) compared to the values predicted by the LR model (dark-blue violins) using the validation dataset. In particular, for video game controller no. 1 (the first two violins), it can be seen that the median (represented by a black line) observed value for the pair traditional-modern (upper chart) is approximately 3 (light-blue violin), while the median predicted value (dark-blue violin) is slightly above 3. Moreover, both behaviours are similar, indicating the optimal quality of the proposed model.

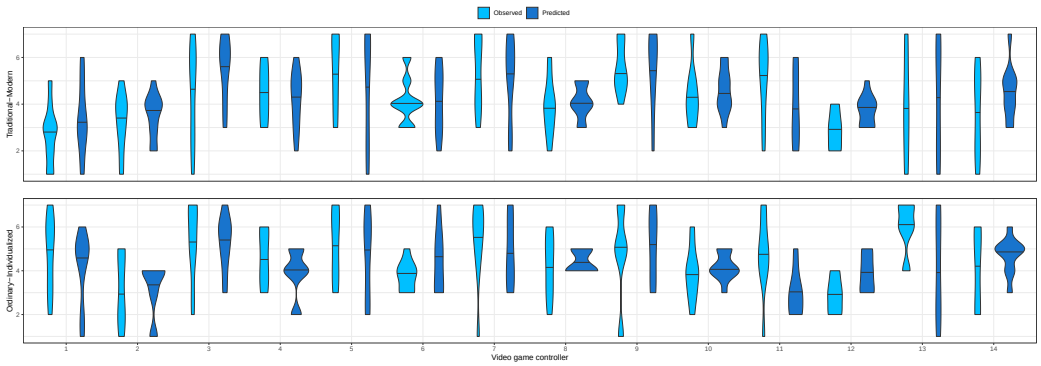


Figure 10. Observed (light-blue violins) and predicted (dark-blue violins) values of the Kansei pairs traditional-modern (upper chart) and ordinary-individualised (lower chart) for each video game controller. Black lines represent median values.

As we mentioned previously, our goal was to propose an ergonomic design. To achieve this, we developed a linear regression model that relates the pair ergonomic-procrustean (*EP*) with the Kansei pairs traditional-modern (*TM*) and ordinary-individualised (*OI*). This model is defined as:

$$EP = -2.377 \cdot TM + 1.806 \cdot OI \quad (1)$$

This linear regression model indicates that an ergonomic video game controller is associated with a modern design. Specifically, if the value of the Kansei pair traditional-modern increases by one unit, the pair ergonomic-procrustean, on average, decreases by 2.377 units. Also, Figure 11 shows the values predicted using Equation (1) (dark-blue violins) alongside the observed values (light-blue violins).

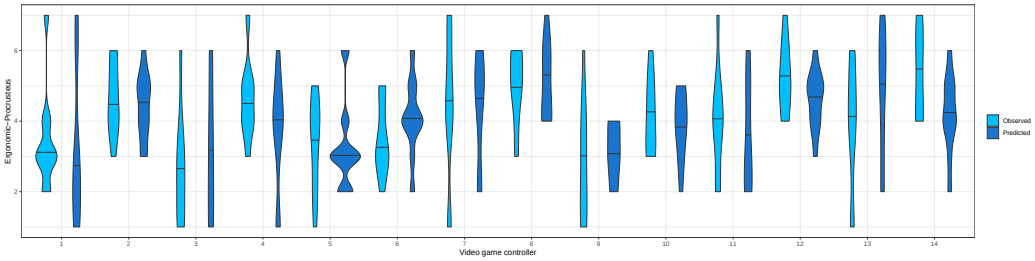


Figure 11. Values of observed (light-blue violins) and predicted (dark-blue violins) of Kansei pair ergonomic-procrustean for each video game controller. Black lines represent median values.

4.2. Linear Regression Model for Coordinates

The coordinates (p_x, p_y) of different points on video game controllers (Table 2) are the independent variables for the linear regression model proposed for the Kansei words of interest. For the original design of the video game controller, the values of different coordinates are shown in Table 5. These values are measured in millimetres (mm). In this model, the least-squares method is used to find a solution, with each coordinate corresponding to the factor variables listed in Table 6.

Table 5. Coordinates (p_x, p_y) of different points on the original design of the video game controller.

Coordinate	p_1.	p_2.	p_3.	p_4.	p_5.	p_6.	p_7.	p_8.	R_1	R_2
$p_{\cdot x}$	2.2	2.2	12.2	12.2	10.2	4.2	0.0	14.4	6.3	19.0
$p_{\cdot y}$	0.0	11.8	11.8	0.0	7.0	7.0	9.0	9.0		

Values are measured in mm.

Table 6. Linear regression model.

Kansei Pair	Linear Regression Model
Traditional-Modern	$2.479p_{1x} - 1.181p_{1y} + 0.776p_{2x} + 0.504p_{2y} + 1.249p_{3x} + 2.270p_{4x} - 2.523p_{5x} + 2.997p_{5y} - 2.607p_{6x} - 2.831p_{6y} - 0.500p_{7y} - 1.067p_{8x}$
Ordinary-Individualised	$1.489 + 3.813p_{1x} - 1.226p_{1y} + 0.291p_{2y} + 4.329p_{4x} - 0.131p_{6y} - 4.711p_{7x} - 4.474p_{8x} - 0.019R_2$

The coefficients appearing in the above equations represent the average change in the Kansei word pairs. For instance, in the equation for the pair traditional-modern, the coefficient 2.479 associated with the p_{1x} coordinate indicates that when this increases by one unit, the value of the adjective increases, on average, by 2.479 units.

Using both linear models, we can make predictions for the Kansei words of interest in order to enhance the proposed design. As mentioned, our goal is to achieve a modern and individualised design that improves ergonomics. Therefore, we need to enhance the values of the traditional-modern pair and maintain or slightly improve the values of the ordinary-individualised pair.

5. Discussion

Based on this study, an average shape, obtained from the shells of the three video game controllers (nos. 3, 13, and 14), was created to propose improvements for a redesign. A comparative study was conducted with the final shape to redesign the controller, incorporating the improvements identified in the final video game controllers. Conceptually, the shapes of these controllers were merged step by step, as shown in Figure 12. The three levels that can be seen in the figure correspond to the three phases considered: the first two represent the phases of the mathematical model, while the third shows the evolution of the design based on the designer's criteria, based on Kansei Engineering.

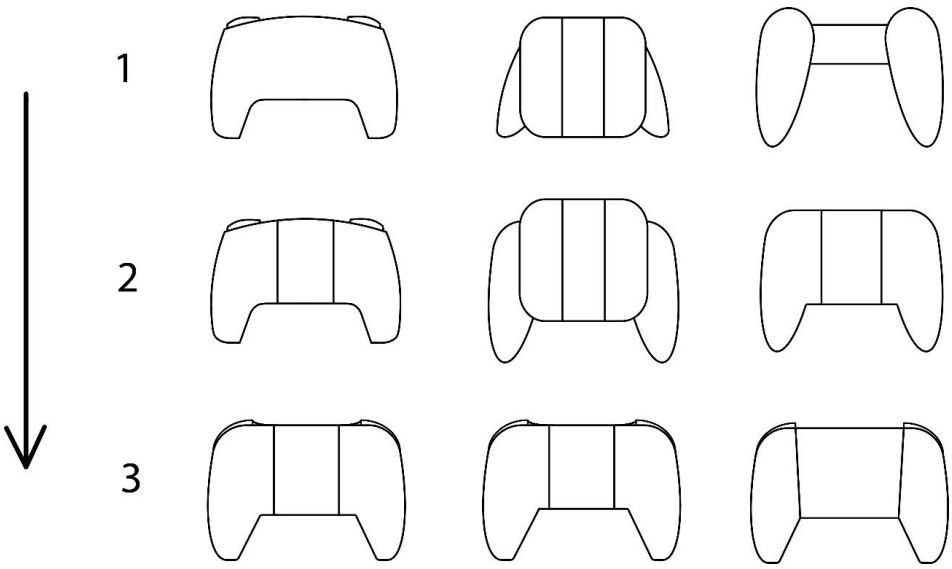
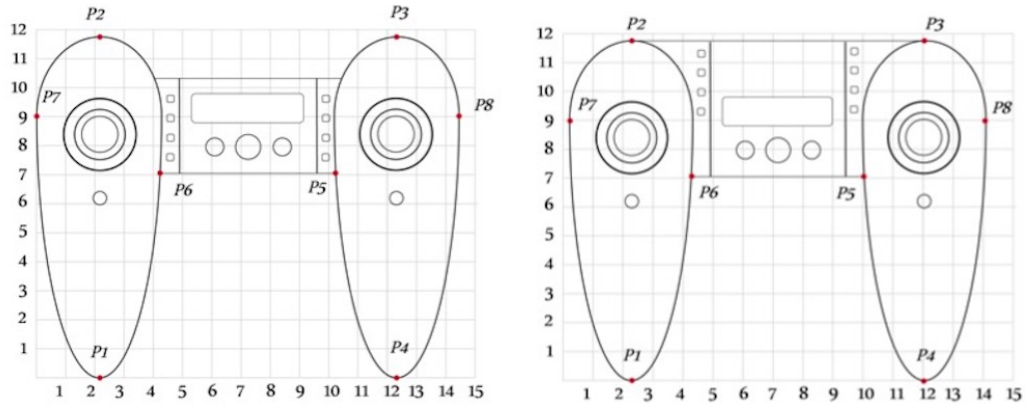


Figure 12. Resulting shapes.

In this study, we show how changes in the coordinates affect the design of the video game controller (Figures 13–18) and classify the surveyed controllers according to the mean values of the words of interest (Table 7). The first five entries correspond to the applied mathematical model, while the last entry shows the evolution of the design presented by the designer after applying the method, following criteria developed in the creative phase of their professional discipline.

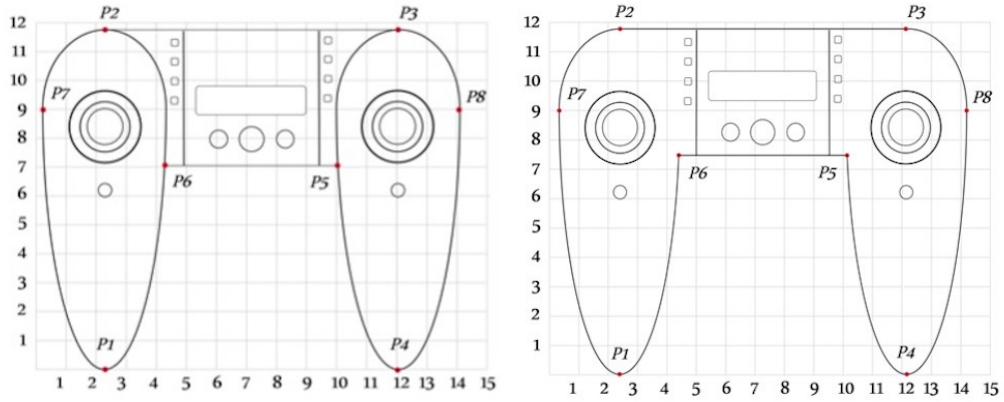


(**a**) Original design (**b**) Design 1

Figure 13. Evolution of the original design to Design 1. The p_{7x} coordinate was MODIFIED from 0.0 mm to 0.1 mm.

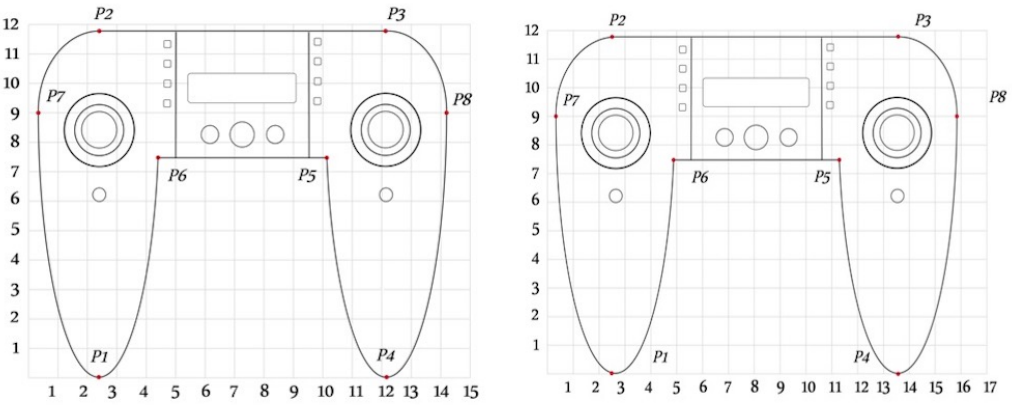
In Table 7, it can be observed that the designed controller (no. 14) improves its position compared to the initial design using traditional methodology. This new design presents modern, individualised, and ergonomic features.

The final result, after applying Kansei, can be seen in Figure 19, which compares the original model with the one obtained in this study. As seen in the image, although the dimensions of both products are similar in both width and height, there is a substantial difference in the number and position of the buttons on each controller, which highlights that the product's functionality was partly neglected in the initial market study used for the traditional design, which prioritised other aspects. Emotional design has been an important factor in obtaining these modifications to the preliminary design. It has supported us in taking a clear, user-centred approach, as other authors have discussed [42–44].



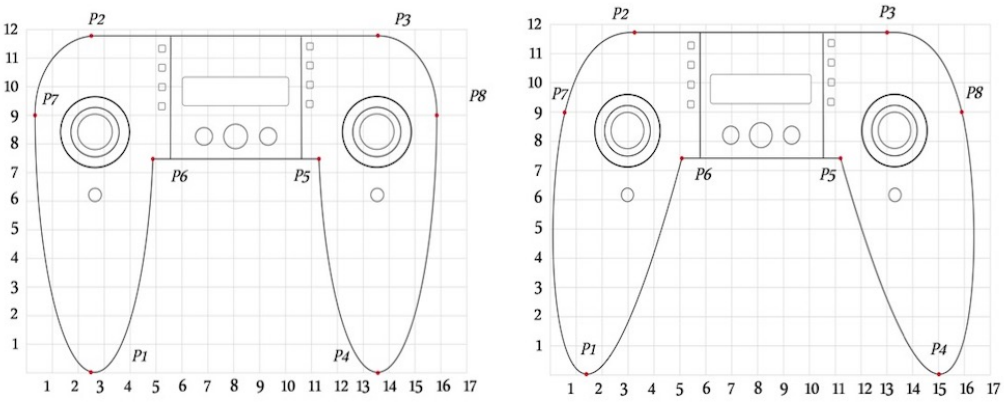
(**a**) Design 1 (**b**) Design 2

Figure 14. Evolution of Design 1 to Design 2. The p_{5y} and p_{6y} coordinates were MODIFIED from 7.0 mm to 7.5 mm.



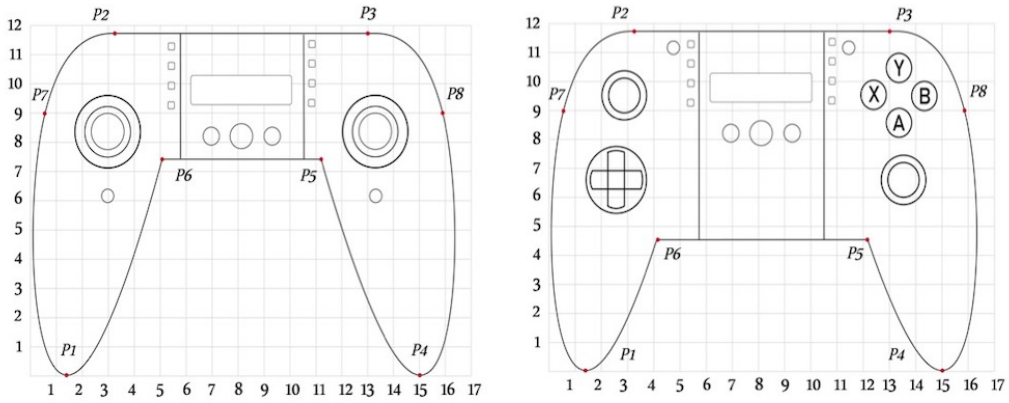
(**a**) Design 2 (**b**) Design 3

Figure 15. Evolution of Design 2 to Design 3. The p_{4x} coordinate was MODIFIED from 12.2 mm to 13.5 mm.



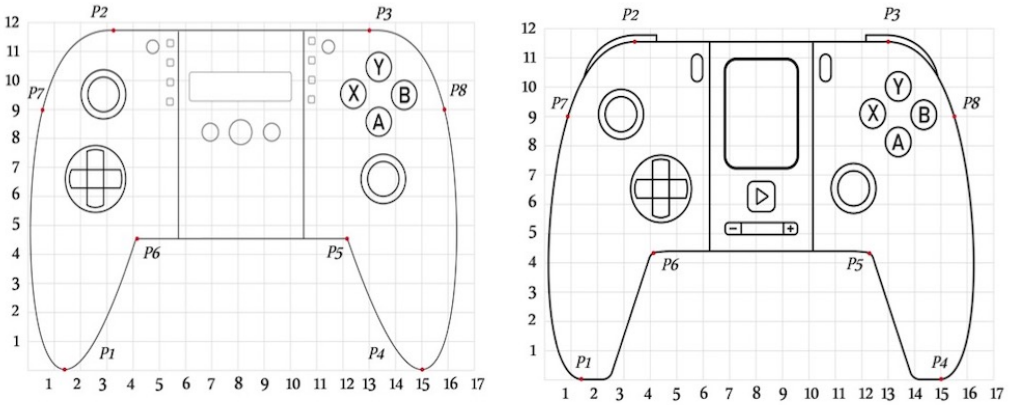
(**a**) Design 3 (**b**) Design 4

Figure 16. Evolution of Design 3 to Design 4. The p_{3x} coordinate was MODIFIED from 12.2 mm to 13 mm.



(**a**) Design 4 (**b**) Design 5

Figure 17. Evolution Design 4 to Design 5: The p_{5y} and p_{6y} coordinates were MODIFIED from 7.5 mm to 4.5 mm.



(**a**) Design 5 (**b**) Kansei redesign

Figure 18. Evolution of Design 5 to Kansei redesigned video game controller. The product design phase included the following changes: greater rounding of the envelope and flattening of the lower peaks; no changes in the coordinates; and adjustments to the central layout.

Table 7. Classification of video game controllers surveyed with final changes in coordinates. The redesigned video game controller is shown in bold.

	Design 5													
Ranking	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**13th**	**14th**
Traditional-Modern	**14**	12	11	6	2	3	4	9	8	13	1	10	5	7
Ordinary-Individualised	**14**	11	3	12	9	8	2	6	7	13	4	10	1	5
Ergonomic-Procrustean	**14**	2	3	6	11	12	1	4	10	13	8	9	5	7

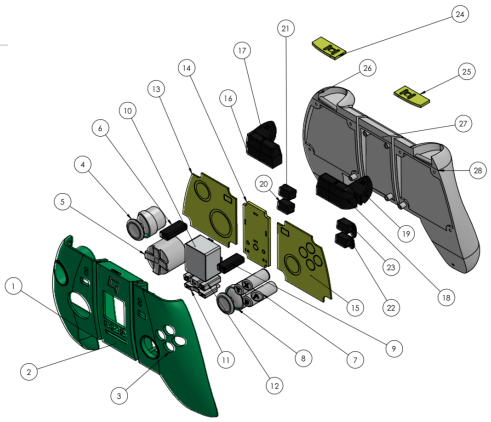
In the initial design, functional buttons were eliminated and later reinstated, and the lower buttons were positioned in a location not easily accessible to the fingertips. This was corrected in the redesign based on Kansei Engineering, with a more classic-looking button panel and the four lower buttons positioned in the flattest area so they can be easily reached (Figure 20).

Although both products are visually appealing to the user, the KE version provides aesthetic harmony and better integration of the controller modules. Similarly, the version obtained in this work is highly rigid, which is advantageous for a product constantly subjected to stresses or shocks. In terms of grip, the KE version also provides a better grip

with a rough surface not contemplated in the traditional design. The final result meets the critical objectives of an ergonomic grip and a pleasant feel while also meeting the requirements for an aesthetically pleasing design, a robust and rigid product to withstand impacts and deformations, and compatibility with various systems/consoles.

Figure 19. Original game controller (**left**) vs. Kansei redesigned game controller (**right**).

To conclude the discussion section, we would like to comment on the limitations we encountered in our work, as we did not have a real physical model to validate the design we achieved. Currently, our research is progressing to new phases through experimentation with physical models derived from the final design achieved here. We intend to validate the results obtained by reapplying the mathematical model to the same population but using the real model as a reference.



Reference number	Name	Number of units	Reference number	Name	Number of units
1	Left casing	1	15	Right motherboard	1
2	Center casing	1	16	L button	1
3	Right casing	1	17	LT button	1
4	Left joystick	1	18	R button	1
5	Crosshead	1	19	RT button	1
6	Select	1	20	ZL button	1
7	ABXY buttons	4	21	ZLT button	1
8	Right joystick	1	22	ZR button	1
9	Start	1	23	ZRT button	1
10	Screen	1	24	Left trigger board	1
11	Volume	1	25	Right trigger board	1
12	Playback control	1	26	Left casing base	1
13	Left motherboard	1	27	Center casing base	1
14	Center motherboard	1	28	Right casing base	1

Figure 20. Expanded view of control system with component table.

6. Conclusions

The Kansei methodology and statistical techniques, including principal component analysis (PCA), and linear regression (LR), allowed us to optimise the shape of the video game controller obtained using the traditional methodology to showcase a design that produces a modern and individualised emotion. PCA allows for the classification of the Kansei words into three factors, explaining over 60% of the available information. The LR model proposed examines the interest pairs of adjectives (traditional-modern and ordinary-individualised) and three factors obtained by PCA to improve the ergonomic aspects of video game controllers. These models provide results similar to the values observed in the surveys performed. In order to achieve an optimal design shape, the proposed LR model, which relates the Kansei words of interest to the coordinates of the points on the video game controller, allowed us to understand the influence of different coordinates on the shape. By modifying these coordinates within this model, we obtained a design with modern, individualised, and ergonomic aspects. The Kansei redesign was validated with a second survey involving the same individuals. Based on the results obtained, the new video game controller design improved its rating for the traditional-modern adjective, confirming the modern aspect of the redesign. However, for the ordinary-individualised and ergonomic-procrustean adjectives, the results remained consistent with those obtained from the original design.

Regarding the ergonomics of the video game controller, the similarity in results compared to the original design can be attributed to the difficulty of accurately assessing this emotion solely through a photograph.

The Kansei methodology has been successful in aligning with the user's perception of the product. This has resulted in enhanced functional features and a better ergonomic textured grip suitable for people with both large and small hands, while also preventing the grip surface from being slippery.

Finally, we can extrapolate everything achieved in this study to any product that is capable of being improved through a design process. The application of Kansei Engineering guides us through a mathematical process that ensures objectivity regarding the type of product.

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