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RESEARCH ARTICLE

Design of a smart garment for fencing: measuring attractiveness using the AttrakDiff Mini method

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Abstract
In this study, a new hypothesis for the design of a smart fencing garment, developed through a user-centred design process, is presented and a pre-evaluation of the design by applying the AttrakDiff Mini method is proposed. With the Portuguese Fencing Federation's support, a survey was shared with the 37 affiliated weapons rooms. It was possible to validate 36 participations, 54.1% men ($n = 20$) and 45.9% women ($n = 16$) residing in Portugal. The questionnaire consists of 4 scales, divided into 10 items that made it possible to assess the hypothesis' usability, identity, stimulation, and attractiveness. It is statistically possible to quantify the relationship between the dependent variable (attractiveness) and the independent variables (pragmatic quality, hedonic quality-identity, hedonic quality-stimulation), such as the correlations between these variables. At the end of the analysis, it was possible to conclude that the participants evaluate the hypothesis positively, considering the envisioned fencing suit possible to use and attractive.

Keywords AttrakDiff · Design process · E-textiles · Fencing sport · Smart garments

1 Introduction

According to Rambausek (2014), smart textiles and smart clothes are now well-known in the textile sector community. This industry sees an opportunity to develop a new category of products and, together with related industries, understands that the bet on smart textile products could be a key for the future. In the editorial "Wearable computing techniques for smart health", Kumar et al. (2020) synthesize wearable computing as the study or practise of inventing, designing, and building sensors supported by the body through the miniaturization of computational devices. Devices that can provide specific and limited information, such as monitoring heart rate, measuring walking speed, or even more advanced functions such as motion recording. A "wearable computer" that, according to Mann (1996), can be used underneath, on or in clothes.

Smart clothes are part of a new focus of attention that runs between Information and communications technology (ICT) (Ferscha et al. 2014; Buchwald et al. 2018) and Internet of Things (IoT) platforms (Swan 2012; Hiremath et al. 2014; Fernández-Caramés and Fraga-Lamas 2018). For Post and Orth (1997), the combination of areas and branches of activity leads to the evolution and creation of new products, solving challenges that offer new business opportunities, and challenges that need further investigation, development, experimentation, and validation. In this perspective, smart clothes integrate high technological components throughout the design process, in addition to the substantial implications in the interdisciplinary sphere of human-computer interaction (Lupton 2014), electronic textile technologies, interaction design, and wearability. Human-computer interaction (HCI) is a multidisciplinary practice that focuses on interactions between the user and the computer (hardware and software) to create accessible, functional, efficient, safe systems and interfaces. According to Kolko (2011), interaction design creates a dialogue of a physical and emotional nature between the user and the product, system, or service; it manifests itself in the interaction between form, function, and technology. Whether in the development of clothing, device, or a computer program, one of the principles is empathising with the user.

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A functional artefact becomes useless without a user, and effort, time, and money will have been wasted throughout the design process. According to Hekkert and McDonagh (2003), the experiences are unique, composed of small acts related to contexts, people, and products; these experiences cannot be projected, only interactions with users. For McLellan (2000), experience design aims to create knowledge obtained through the practice of the user's experiences. These are not only functional and objective but also engaging, attractive, memorable, and pleasant.

Considering the area of sports, our studies revealed a research gap in fencing. This sport has not been targeted in the field of smart clothing, in contrast to other sports that already benefit from these concepts and technologies. Based on the user's experience, this study intends to validate a set of qualities regarding smart fencing clothing (i.e. pragmatic, hedonic of identity/stimulation and attractiveness). By measuring the attitudes of athletes towards the new design of a smart garment with a visual interface (i.e. mobile application), it is intended to understand whether the developed hypothesis fits the user's expectations.

In this sense, this research's fundamental premise is to address practices for a "good design" of an intelligent fencing suit. According to Norman (2014), "Good design is actually a lot harder to notice than poor design, in part because good designs fit our needs so well that the design is invisible, serving us without drawing attention to itself. Bad design, on the other hand, screams out its inadequacies, making itself very noticeable." Thus, a "good design" makes the smart garment useful, understandable, and innovative, and at the same time aesthetically pleasing, without being explicit. This proposition is based on a user-focused design process where the application of the user-centred design (UCD) model is predominant, through tools that relate to the user and mix research methods by questionnaire, interview, and observation. The goal is to question and learn what can work or what cannot improve the design—thus involving the user in the phases of the design and evaluation process.

2 Design of a smart garment for fencing

The hypothesis presented for the AVANTGARDE fencing suit (Fig. 1) combines two electronic systems that provide different feedback types (Fig. 2). The first interactive system detects the foil's touch using flexible piezoresistive pressure sensors integrated into the textile, providing real-time feedback on the validity/scoring of the touch, and measuring different intensities and durations of pressure.

The second system captures the athlete's body movements through rigid inertial sensors (IMU) adopted in the textile, providing, through wireless communication, free 360° playing and real-time feedback of the athlete's three-dimensional movements.

The overall design of the fencing suit is determined by the location of the IMU sensors, most visible on the extremities of the body (e.g. head, hands, feet). In addition to integrating wearable technologies, the garment consists of a unique piece, unlike the existing layered suit. The modelling size varies according to gender. Fabric must be developed to conform to the standards of the International Fencing Federation (FIE); to integrate these technologies, the fabric must be an elastic, breathable Kevlar with a resistance of 350 Newtons (training) and 800 Newtons (competition).

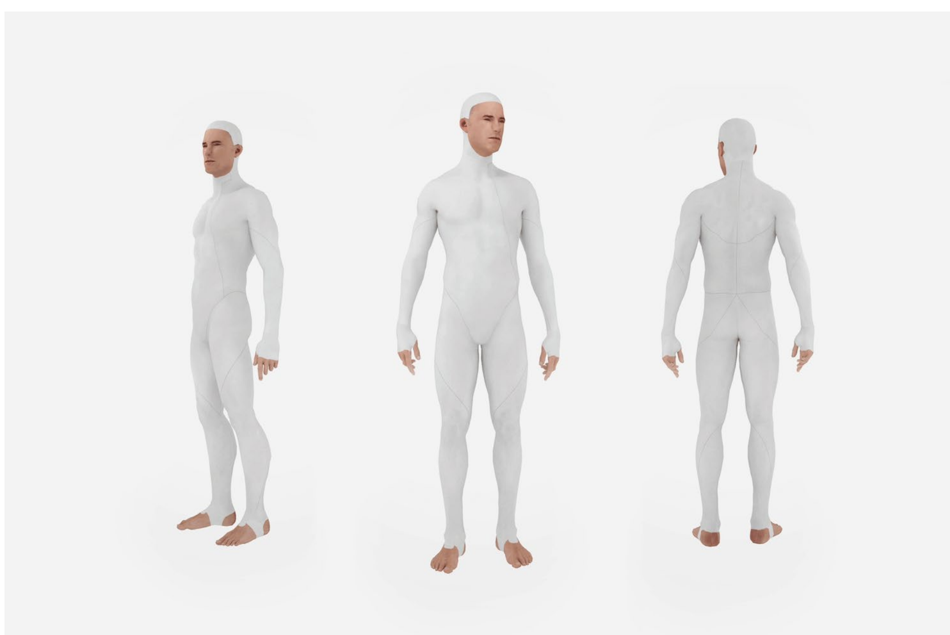

Fig. 1 Screenshots of the 360° video

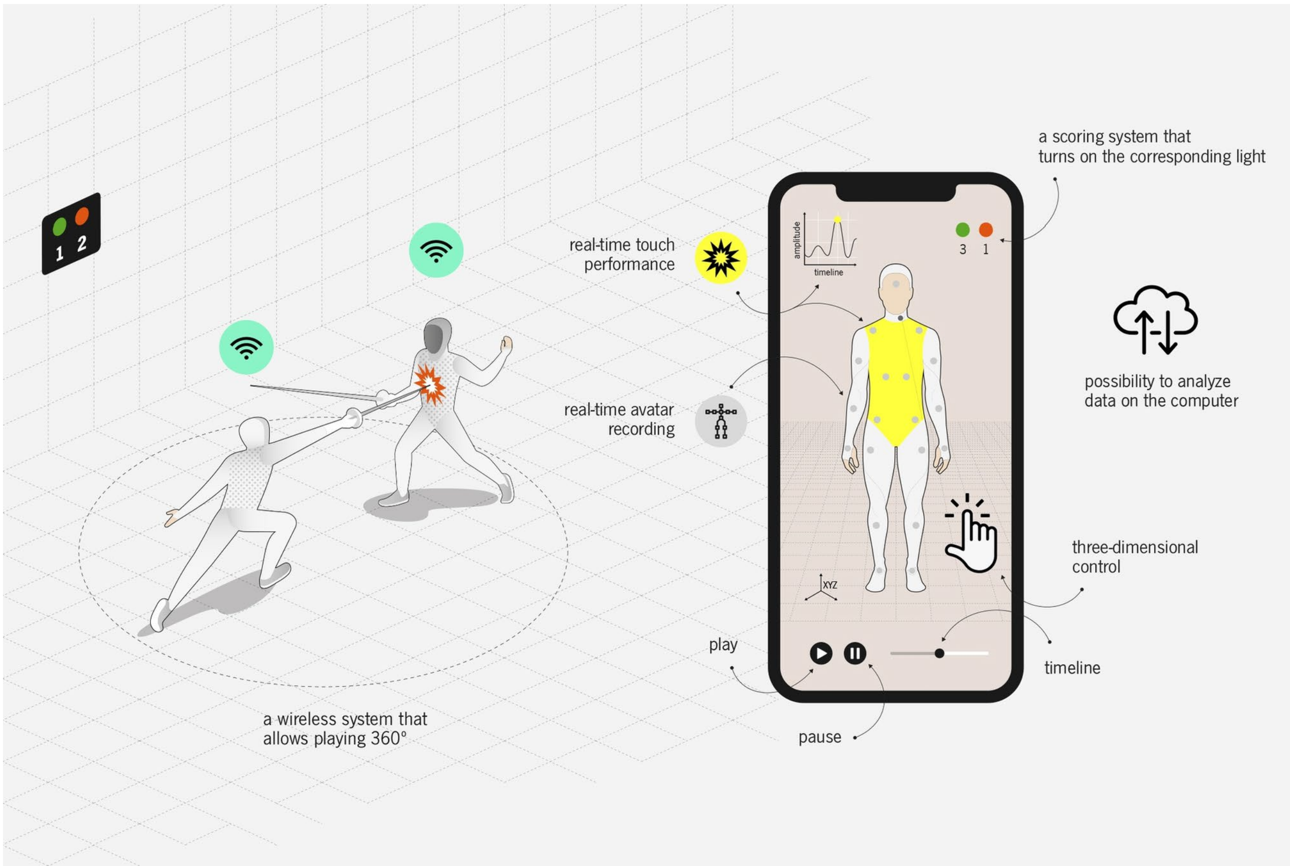

Fig. 2 Infographics of the hypothesis

This fencing suit must first be turned on and then wirelessly paired with the external hardware. Sensors must relate to the scoring system at the same time with the smartphone (i.e. referee and coach), through an application, with the possibility of the information being analysed on a computer.

In literature, we find several definitions for the term validation, be it the act of validating, confirming, or approving; the question arises: "Does the user really desire the hypothetical fencing suit?". This doubt drives the need for a method that assesses the hypothesis' result.

3 AttrakDiff Mini

AttrakDiff Mini is a short evaluation questionnaire (10 items) that analyses the perceived pragmatic quality, the hedonic quality, and the attractiveness of an interactive product. The attributes are evaluated using the 7-scale Likert bipolar semantic differential method representing opposites (negative/positive). The middle value is 0, the leftmost value – 3, and the rightmost value + 3. Through the application of the compact version (Hassenzahl et al. 2008; Hassenzahl and Monk 2010), it is intended to confirm whether the hypothesis' attractiveness is positive. Originating in the AttrakDiff version of 28 items (Hassenzahl 2003; Hassenzahl 2004) and originally developed in German, the AttrakDiff questionnaire has already been translated into several languages. However, in literature, it was not possible to find a rigorous translation of the AttrakDiff Mini into Portuguese. The resources used for a translation were adapted from the AttrakDiff 2 version of 21 items (Hassenzahl et al. 2003) translated by Carneiro (2018).

The AttrakDiff Mini was chosen because it is a method already used to assess the user experience of entertainment applications for measuring the visual usability, identity, stimulation, and attractiveness, namely, mobile applications with a visual interface, using self-report bipolar subitems (English version) that represent opposite principles (Silvennoinen et al. 2014; Holzer et al. 2015; Fiebig et al. 2016; Minge et al. 2017; Fischer et al. 2018). Despite no relevant articles were found that applied the AttrakDiff Mini in the study of smart garments, the hypothesis described in this work includes a visual interface in a mobile app. Furthermore, the remaining elements of the hypothesis comprise visual assessment and technological functionalities very much related to those of entertainment applications. Using this model allowed the study of the new hypothesis, contributing important information to a sport that is little explored in the field of smart textiles, supporting the production of a prototype. The hypothesis assessment by the users was based on the observation of 3D video and 2D infographics, both with an explanatory paragraph.

4 Data collection method

4.1 Sampling

Through the Portuguese Fencing Federation's support, an online survey was shared with the 37 affiliated rooms of arms. After presenting the hypothesis for the fencing suit through infographics and 360° video, participants were asked to answer the AttrakDiff Mini questionnaire. Initially, 42 questionnaires were collected, of which 36 could be validated as correct and unique. The 36 valid participants are 54.1% men ($n = 20$) and 45.9% women ($n = 16$) residing in Portugal. Of the five age groups, youth correspond to 16.7% ($n = 6$) of the study participants, cadets to 8.3% ($n = 3$), juniors 22.2% ($n = 8$), seniors 36.1% ($n = 13$), and veterans 16.7% ($n = 6$). Data were collected from 15 February to 15 March 2021.

According to the Portuguese Fencing Federation, the affiliated athletes in 2020 are 123 youths, 117 cadets, 72 juniors, 108 seniors, and 56 veterans, with the total number of 476 athletes. Also, the modality is mainly constituted by athletes with less experience (i.e. youths and cadets). The 36 participants correspond to a 15% margin of error at a 95% confidence level. The online questionnaire comprised 75% of responses in the older, more experienced age (i.e. juniors 22.2%, seniors 36.1%, veterans 16.7%).

4.2 Structure of the inquiry

In addition to respecting the structure of the AttrakDiff Mini questionnaire, it is divided into 4 scales: pragmatic quality (PQ), from the 1st to the 4th item, describes the usability of the product and indicates the perceived level of ease of the user in achieving his goals; hedonic quality-identity (HQ-I), from the 5th to the 6th item, indicates the extent to which the product supports a social function and communicates a specific identity of the user; hedonic quality-stimulation (HQ-S), from the 7th to the 8th item, indicates how the product supports the need for stimulation, providing new, exciting, and stimulating content, characteristics, and styles of interaction; and finally, attractiveness (ATT), from the 9th to the 10th item, describes the total perceived value of the product based on the perception of pragmatic and hedonic qualities. The items can be observed in Table 1.

Table 1 Descriptive statistics for all items of AttrakDiff Mini (Portuguese/English)

	M	*SD*	*MDN*	*IQR*
Pragmatic Quality (PQ)				
Não é possível usar – Possível usar Impractical – Practical	5.22	1.15	5.00	1.00
Imprevisível – Previsível Unpredictable – Predictable	4.47	1.50	5.00	3.00
Confuso – Bem estruturado Confusing – Clearly structured	5.47	1.56	6.00	3.00
Complicado – Simples Complicated – Simple	4.67	1.80	5.00	3.00
	4.96	1.27	5.25	1.94
Hedonic Quality-Identity (HQ-I)				
Vulgar – Elegante Tacky – Stylish	5.86	1.18	6.00	2.00
De baixa qualidade – De primeira qualidade Cheap – Premium	5.83	1.18	6.00	2.00
	5.85	1.01	6.00	1.00
Hedonic Quality-Stimulation (HQ-S)				
Sem imaginação – Criativo Unimaginative – Creative	6.47	0.88	7.00	1.00
Aborrecido – Cativante Dull – Captivating	6.36	0.83	7.00	1.00
	6.42	0.73	6.50	1.00
Attractiveness (ATT)				
Feio – Bonito Ugly – Attractive	5.58	1.11	6.00	1.00
Mau – Bom Bad – Good	5.89	1.11	6.00	2.00
	5.74	0.87	6.00	1.50

4.3 Description and analysis of the collected data

Before starting the preliminary analysis of the survey data by questionnaire, all items had to be transferred to four scales: pragmatic quality, hedonic quality-identity, hedonic quality-stimulation, and attractiveness, making it possible to determine the reliability of the responses in each scale as well as its distribution. Cronbach's alpha coefficient (α) measured the reliability of the responses in the four scales. This indicator checks whether the study is free of random errors. According to the literature, depending on the purpose of the scale, different reliability levels are required, with a value of $\alpha \geq 0.70$ being recommended. This value is dependent on the number of items that build the scale, and when it is low (less than 10 items), the inter-item correlation values should be $r \geq 0.40$ (Pallant 2007).

In the first part of the analysis, the objective was to collect quantitative data, later analysed with the aid of graphs. The analysis was also carried out according to the AttrakDiff method through the word pairs' description (Ribeiro and Providência 2021), complemented with boxplots with median and interquartile range.

In the second part, all statistical analyses were performed using the SPSS software (version 25). Here, the normality tests performed confirmed a non-normal distribution in the statistics. Therefore, the factorial structure must be evaluated through non-parametric ordinal regression analysis. As a predictive analysis, ordinal regression describes the data and explains the relationship between a dependent variable (ATT) and independent variables (PQ, HQ-I, HQ-S). Finally, the relationship between variables is analysed through the correlation between scales.

5 Results

5.1 Internal consistency analysis

The pragmatic quality (PQ) scale consists of 4 items; the quotations on this scale showed good internal consistency with a coefficient of $\alpha = 0.85$ and an average inter-item correlation of $r = 0.61$, which suggests a strong relationship between the 4 items. Next, both the hedonic quality-identity (HQ-I) scale and the hedonic quality-stimulation (HQ-S) scale are composed of 2 items, and a similar coefficient of $\alpha = 0.63$ and a mean inter-item correlation of $r = 0.46$ also have a positive relationship > 0.40. Finally, the attractiveness (ATT) scale consists of 2 items, with a coefficient of $\alpha = 0.53$ and mean inter-item correlation of $r = 0.42$ showing a positive relationship > 0.40. Except for the PQ scale with a value > 0.70, in the remaining scales HQ-I, HQ-S, and ATT (all with 2 items), the alpha coefficient values are < 0.70, but the mean inter-item correlation value > 0.40.

5.2 AttrakDiff Mini analysis

For a first analysis of the AttrakDiff Mini results, the group's mean scores, standard deviation, median, and interquartile range were analysed. Each scale's median value was considered a neutral score; scores around the neutral score are moderate, scores higher than neutral are positive, and lower than neutral are negative. For data analysis in SPSS software, the scale applied between − 3 and 3 had to be converted in a scale ranging from 1 to 7, with 4 being the neutral score. Table 1 shows the mean (M), standard deviation (SD), median (MDN), and interquartile range (IQR) for each item.

Through average values, the positivity of the product's attractiveness is confirmed in terms of usability and appearance. All scales are of positive semantics, HQ-I and HQ-S having the highest value. From the perspective of the word pairs' description (Fig. 3), the average value of each

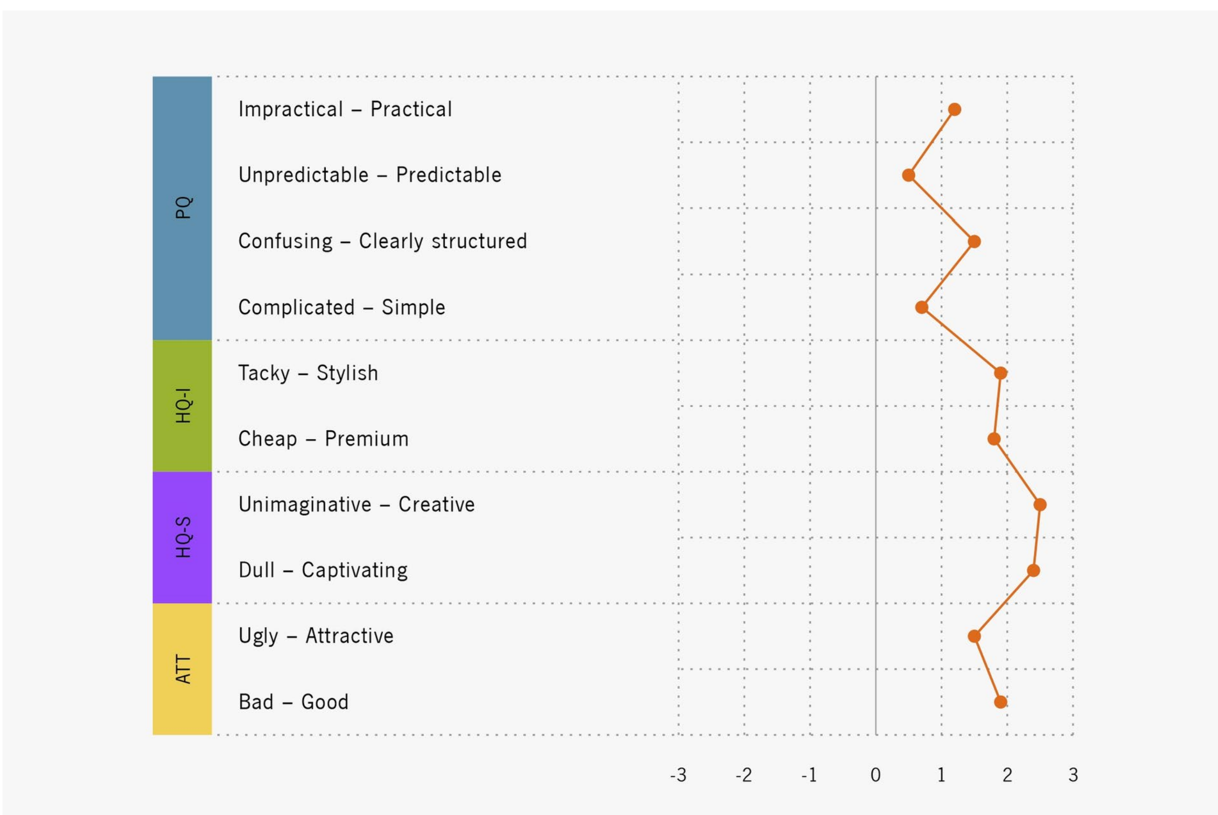

Fig. 3 Description of word pairs

word pair was evaluated. It is possible to perceive that the experience is considered positive, with good attractiveness.

The pragmatic quality scale results indicate that the participants evaluate positively (MDN = 5.25, IQR = 1.94), considering the hypothesis to be practical, clearly structured, and simple, but predictable (MDN = 4.47). This positive value of predictability may be evidence of the user-centred method's efficiency applied to the hypothesis design. In the hedonic quality-identity scale, the results indicate that the participants also evaluated positively (MDN = 6, IQR = 1) considering the hypothesis elegant and high quality. Once again, on the hedonic quality-stimulation scale, participants considered it a creative and engaging hypothesis (MDN = 6.5, IQR = 1). Finally, on the attractiveness scale, participants rate positively (MDN = 6, IQR = 1.5), considering the hypothesis to be attractive and of "good design" (as previously defined). A boxplot graphical representation (Fig. 4) of a data set allows evaluating their dispersion, quickly highlighting the outliers.

5.3 Analysis of the relationships between scales

Subsequently, the mean of results in each of the four scales was determined. The Kolmogorov-Smirnov test was used to validate whether the variables follow a normal distribution. The tests show non-significant results. The p value is less than 0.05 in all cases meaning that the distribution is not normal (Table 2).

After verifying the scales' reliability and confirming that the observed data have a non-normal distribution, the non-parametric statistical technique used to explore the variables' relationships was the regression ordinal and correlation.

The validation of the construct will consist of verifying whether the dimension of attractiveness is predicted by the perception of pragmatic and hedonic attributes. It is expected to classify attractiveness and specifies whether attractiveness is a judgment that arises from the perception of pragmatic and hedonic attributes. This hypothesis implies quantifying a significant dependence between the dependent variable (ATT) and the independent variables (PQ, HQ-I, HQ-S). Through literature, we know that in a null hypothesis, often denoted H0, $p > 0.05$ and an alternative hypothesis, often denoted H1, $p < 0.05$. The p value can take on a value between 0 and 1: (i) significance level 0.1 (= 10%), weak evidence against H0; (ii) significance level 0.05 (= 5%), strong evidence against H0; and (iii) significance level 0.01 (= 1%), very strong evidence against H0.

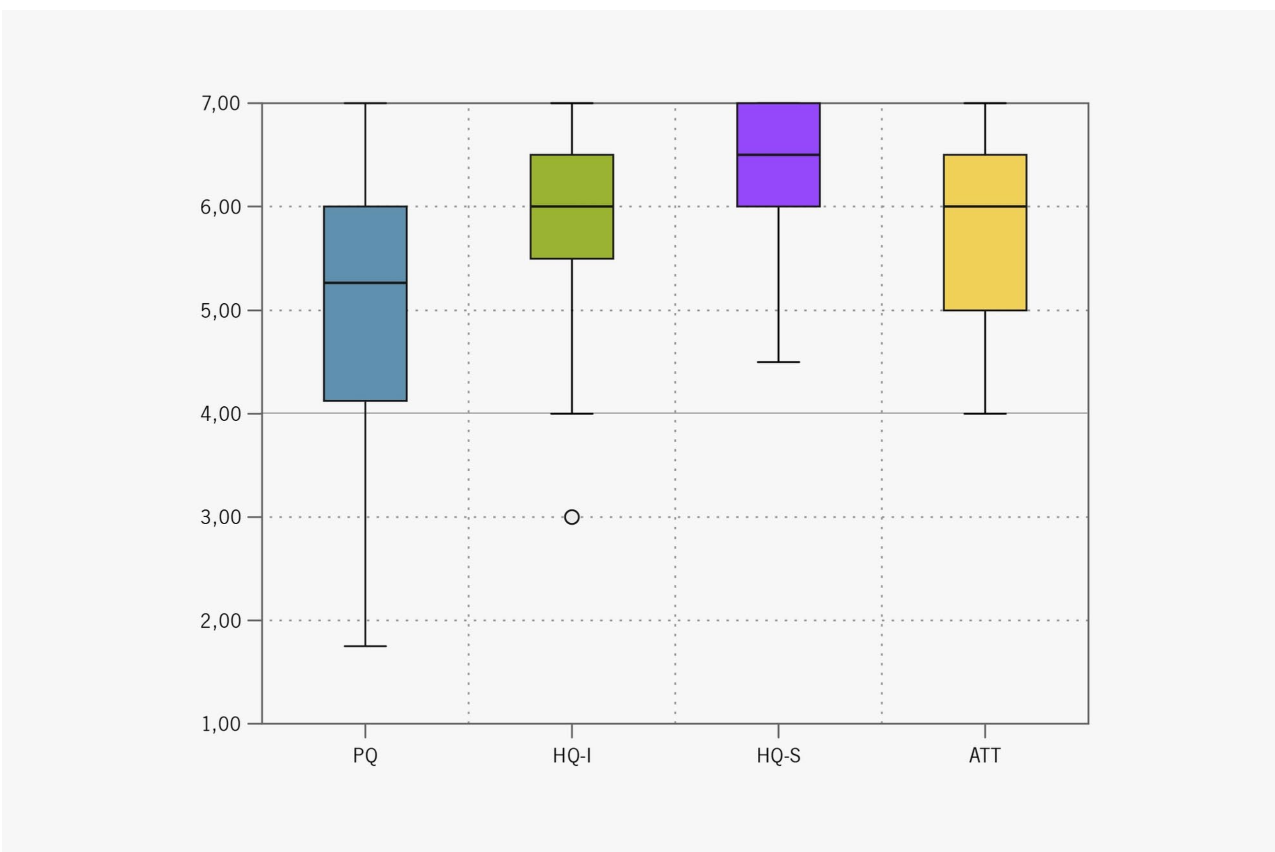

Fig. 4 Boxplots with median and interquartile range

Table 2 Normality tests

	Kolmogorov-Smirnov		
	Statistic	*df*	*Sig.*
PQ (mean)	.151	36	.038
HQ-I (mean)	.171	36	.010
HQ-S (mean)	.259	36	.000
ATT (mean)	.175	36	.007

5.3.1 Ordinal regression

The first condition for showing a dependence between the dependent and the independent variables (Table 3) is that the significance of the p value (model fitting information) must be < 0.05. It was observed that the p value is very small Sig. = 0.000, thus highly significant < 0.05, with very strong evidence of rejection of the null hypothesis (H0). This means that there is a significant dependence between the dependant and the independent variables. The second condition (Table 4) is that the significance of the Pearson value (goodness-of-fit) must be >0.05. The observed data show a Sig. = 0.845, significant value > 0.05. The third condition (Table 5) is that the significance of the Nagelkerke value (pseudo R-square) must be >0.70 for a strong link between the variance of the dependant variable and that of the independent variable. A value of $R2 = 0.665$ is observed, indicating a moderate dependence (ATT) in the regression model.

Table 3 Model fitting information

Model	− 2 log likelihood	Chi-Square	df	Sig.
Intercept Only	133.170			
Final	95.564	37.607	3	.000

Table 4 Goodness-of-fit

	Chi-square	*df*	*Sig.*
Pearson	180.692	201	.845
Deviance	95.564	201	1.000

Table 5 Pseudo R-square

Cox and Snell	.648
Nagelkerke	.665
MacFadden	.282

The fourth condition (Table 6) is to analyse the estimates (β) of the parameters. It is observed that PQ was a predictor of ATT, showing a positive effect of $\beta = 0.412$. The same is observed with HQ-I, showing a positive effect of $\beta = 2.153$ and with HQ-S, showing a positive effect of $\beta = 0.613$. While the exponential value exp(β) for PQ is exp (0.412) = 1.509, it indicates that attractiveness (ATT) increases by a factor of 1.509 for each increase in the unit in PQ. The value for HQ-I is exp (2.153) = 8.614, indicating that attractiveness (ATT) increases by a factor of 8.614 for each increase in the HQ-I unit. The value for HQ-S is exp (0.613) = 1.846, indicating that attractiveness (ATT) increases by a factor of 1.846 for each increase in the unit in HQ-S. Finally, the fifth condition (Table 7) is to perform the parallel line test, in which the value should be > 0.05. We observe Sig. = 0.072.

5.3.2 Spearman's correlation

The correlations between scales are shown in Table 8. The two hedonic scales HQ-I and HQ-S are correlated ($r = 0.508$, $p < 0.01$), showing the two scales' strong semantic connection but still allowing distinction. On the other hand, the PQ scale is also correlated with the hedonic scales HQ-I ($r = 0.418$, $p < 0.05$) and HQ-S ($r = 0.506$, $p < 0.01$). The attractiveness (ATT) scale is also correlated with the PQ scale ($r = 0.471$, $p < 0.01$), with the hedonic scales HQ-I ($r = 0.737$, $p < 0.01$) and HQ-S ($r = 0.619$, $p < 0.01$). The correlations between the scales show that the components of the AttrakDiff Mini complement each other.

6 Discussion

The questionnaire shows an internal consistency of the 4 conditioned scales due to the number of items for each scale being less than 3 (i.e. one condition for measuring the alpha coefficient). With three scales (HQ-I, HQ-S, ATT)

Table 6 Parameter estimates

						95% confidence interval for estimate	
		Estimate	*Std. error*	*df*	*Sig.*	*Lower bound*	*Upper bound*
Location	PQ	.412	.296	1	.165	− .169	.992
	HQ-I	2.153	.556	1	.000	1.064	3.243
	HQ-S	.613	.655	1	.349	− .671	1.896
		Hypothesis test				95% confidence interval for Exp(β)	
		Exp(β)	*Std. error*	*df*	*Sig.*	*Lower*	*Upper*
Location	PQ	1.509	.3113	1	.186	.820	2.778
	HQ-I	8.614	.5672	1	.000	2.834	26.184
	HQ-S	1.846	.6887	1	.374	.479	7.119

Table 7 Test of parallel lines

Model	− 2 Log Likelihood	Chi-square	df	Sig.
Null Hypothesis	95.564			
General	71.940	23.623	15	.072

Table 8 Correlations between scales

	PQ	HQ-I	HQ-S	ATT
Pragmatic Quality (PQ)	1			
Hedonic Quality-Identity (HQ-I)	.418*	1		
Hedonic Quality-Stimulation (HQ-S)	.506**	.508**	1	
Attractiveness (ATT)	.471**	.737**	.619**	1

*$p < 0.05$/**$p < 0.01$

comprising only 2 items each, it was possible to report a > 0.40 relationship between each scale's items through an average inter-item correlation. Spearman's correlation coefficient is used here to discover the monotonic relationship between two ordinal variables, thus understanding the strength and direction of this positive relationship.

The general idea is that one scale influences the experience of the other scale; in this case, it means that there is always a positive association between the two variables, which is demonstrated by the values obtained. For example, the higher the HQ-I, the higher the ATT (strong correlation), followed by the other correlations. The results highlight an issue about the construction of the AttrakDiff Mini tool that is important to discuss and deepen. Here, the increase of one item for each of these 3 scales may benefit the questionnaire's internal consistency. On the other hand, the scales PQ, HQ-I, and HQ-S show a significant connection with the scale ATT, influencing attractiveness and evaluating the hypothesis as attractive. Therefore, the participants have good expectations regarding the product's pragmatic and hedonic qualities. However, this evaluation may vary when the product becomes real and tested.

The AttrakDiff Mini method may be a step in the right direction. It is expected that more people use the model to gain more knowledge about which scales contribute to the assessment of the attractiveness of e-textile solutions.

7 Conclusion

In this work, a reliability study was carried out on a sample of 36 Portuguese fencers to collect quantitative data, essential for analysing the qualities of a hypothesis for smart fencing clothing. This study shows the distinction between the perceived pragmatic quality and the perceived hedonic quality, which combine to generate an assessment of the attractiveness of the hypothesis. The independent variables are analysed over the dependent variable, and several relations have been determined statistically. The results on the four scales indicate that the participants evaluate positively, consider the design possible to use, well-structured, and simple. They also consider the design elegant and with quality. Finally, on the attractiveness scale, participants consider the design attractive and "good". These results very likely stem from the application of the user-centred method for the design of the hypothesis.

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Declarations

Conflict of interest The authors declare no competing interests.

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