HUMAN FACTORS AND ERGONOMIC STUDIES FOR THE CAR MANUFACTURING INDUSTRY

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Abstract *¾ In the car manufacturing industry, the trend is to try to drastically reduce the time-to-market for new products in order to remain competitive. The Robotics Center (Ecole des Mines de Paris) has developed a methodology for the design and evaluation of Virtual Reality (VR) applications. The idea of this experiment is to go beyond the capabilities of traditional ergonomic software by using VR techniques. The major drawback of ergonomic software's such as Safework or Jack is the lack of sense feedback.. The tester is not able to validate the sensation of comfort associated with the commands of the dashboard. This is also true for the IMAVE system. In this context, a large project was initiated by a French car manufacturer and the CEA/LIST (specialized in force feedback systems) to address the following issue: to what extent can the force-feedback systems be used to study the ergonomics of a car? It is essential to take into account the human user while designing the Virtual Environment (VE). The level of his perception outlines the level of realism required. In the case where force feedback is used, a correct model of the haptic loop should contain a dynamic model of the user, as his existence and actions affect decisively the total performance of the system. Based on these aspects, we have used human factor methods in order to reproduce the dynamic characteristics of a push button.*

Index Terms ¾ Human factor, Virtual reality, Haptic rendu, Ergonomic study, Push button.

INTRODUCTION

One of the characteristics of VR based systems, from the control point of view, is that the human is an essential part of the transfer loop because of its quasi continuous and bi-directional interaction with a virtual environment. Therefore, other aspects have to be taken into consideration rather than those classically considered.

Human factors are composed of principles and applications in the fields of ergonomic, aptitude and personal selection, tolerance, adaptation performance, and human performance evaluation, of systems with normal or degraded functioning conditions. It includes biological, physiological, psychological and psychosocial aspects.

PREVIOUS WORKS

[2] The Just Noticeable or Detectable Difference (JND) is an increment (or decrement) of a specific stimuli intensity. While comparing a real and a virtual case, we can consider the PSE, which is the value of the compared stimuli, and is subjectively perceived to be equal to the reference stimuli1

Previous work used the JND or PSE [6] [3] calculation in order to make the compliance or stiffness discrimination. Among the obtained results, we can notice Jones and Hunter2who found that in the case of compliance discrimination the JND is in the order of 23% of the stimuli intensity. Tan has studied the manual compliance discrimination with finger movements by using an electromechanical apparatus. She first found that the JND mean was 8% in the case of a constant grasp distance [5]. After reducing the terminal force feedbacks by using variable grasp distances, the JND mean value increased to 22% [5].

In a VE case, Tzafestas found a JND mean value of 44% (clearly superior to a JND value in a real world) with the use of a dextrous hand master with 14 active phalanx from the LRP [6]. The virtual discrimination was carried out between 2 virtual balls, displayed on a PC screen. The balls were alternatively pressed between the thumb and the four other fingers of the interface.

In all the previous research work that use this kind of approach, the study of a button has been limited to a spring model. In this work, we will investigate the button as a whole system composed of a spring, mass and damping.

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DESCRIPTION [4]

The main drawback of classical ergonomic software such as Safework or Jack is their lack of haptic feeling. The tester is not able to validate the sensation of comfort associated with the commands of the dashboard. This is also true for the IMAVE system. This is the reason why car manufacturers are working on this point in collaboration with robotics group specialized in force feedback systems. In fact they want to know to what extent force-feedback systems can be used in studying the ergonomics of a car?

The aim of this research effort is to reproducethe haptic sense (force feedback in particular) felt by one's fingertip while pressing a real button. The haptic device Phantom Desktop was used in these experiments to explore and interact with a VE in which a button is dynamically represented (Fig. 1). A visual representation of the button which stiffness and stroke can be easily modified is used. In this way we compare a nominal configuration with different ones.

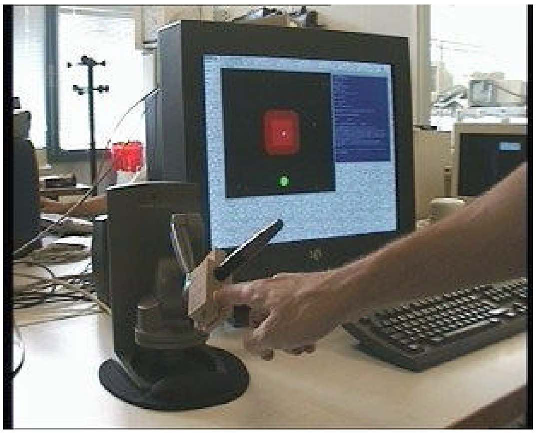

FIGURE. 1
BUTTON SIMULATION WITH PHANTOM DESKTOP

APPROACH AND VALIDATION TESTS [BEN01]

Our approach and the JND approach differ in the final result interpretation. We consider a first step with coarse changes or important enough in order to allow subjects' adaptation to the manipulation. The variations should be made in an uncertain manner, where each configuration should be tested at least three times. Subjects should have the possibility to come back to the nominal configuration as many times as wanted, when they hesitate. If two among the three responses given by a subject about a configuration are true, we can consider that this subject's response is right. At the end, the responses of each subject have to be grouped and the mean between all subjects is calculated. From this final result, the curve representing in general the good responses percentage (rate) variation as a function of the different cases of variation, is drawn. Beside the interpretation of the curve, it permits the calculation of the mean of the Good Response Rate noted by GRR. If in the calculation of the JND mean a small value indicates a good level of discrimination, in the case of the GRR mean a high value indicates a good subject's perception of the greatness judged.

We have planned a total of seven tests that deal with different aspects but without varying all the button's characteristics. In the scene, subjects could perceive a button modelled graphically by 3D polyhedrons (displayed in a red colour) and a small green sphere when the configuration of the button is nominal. but When it passes to a configuration that have to be judged, the sphere becomes red. At the beginning of each test, we explain the principles of the test to each participant, i.e. each time the sphere changes its colour to red, we ask them to estimate:

- The stiffness of the button (test 1)
- The stroke with a constant force (test 2)
- The stroke with a variable force (test 3)
- Its stiffness and its stroke (test 4)
- Its stoke with an axis of translation different from the Z one (test 5)
- The position of the intermediate point between two displacements in order to reproduce a good click sensation (test 6)
- And its blind stroke (test 7) where (the button) he could click at each instant

We remind that subjects could pass from the nominal configuration to any other one, which make them doubting, as many times as wanted.

TESTS RESULTS

In the first test, the number of subjects was 11, among them a girl. Only one person was not right-handed. In the second one, they were 10 with again a girl and a left-handed. For the other tests they were 8, all males with one left-handed again. In all the cases, subjects were either permanents in the laboratory, PhD students or trainees. Their age varied from 20 years old to 34 years old with a mean of 25.6 for the first two tests and 25.125 for the remaining tests.

TEST 1 RESULTS (STIFFNESS DISCRIMINATION)

Remark : we express the nominal value in terms of Newtons although we are talking at the stiffness because the force value is the result at the end of the stroke after stiffness variation. It is a manner to show the interface limits.

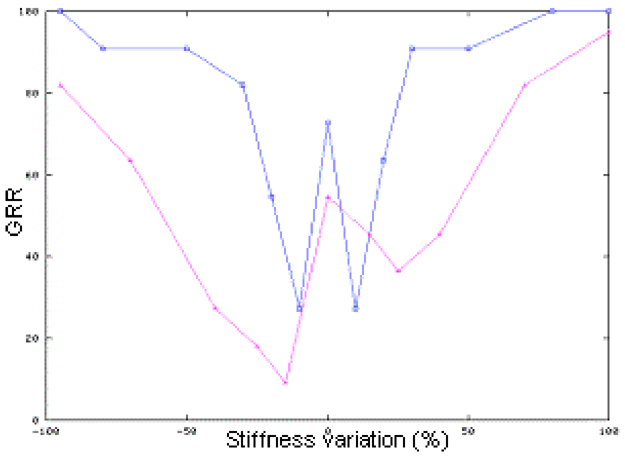

FIGURE. 2
RESPONSE RATE AS A FUNCTION OF THE STIFFNESS VARIATION.

Analysis:

Both curves of figure 2 have the same behaviour. The curve represents the good responses percentage greater than 50% for stiffness variations r, such that r $\in$ [-95, -20]$\cup$[20, 100]%, while the curve (smaller or lower nominal value) this range is reduced to r $\in$ [-95, -70]$\cup$[70, 100]%. For both cases the configuration with no variation represents a peak (much more important than the upper nominal configuration case). We also study an important parameter which is the GRR mean value. This value is greater than 50% in both cases and much more important in the upper nominal configuration case.

Comments:

In both cases, the results show that subjects' responses were good enough for the whole responses except for some stiffness variations r, such that r = {-10, 10, -25, 15, 25}. For both cases, we can see a clear symmetry with respect to the vertical axis which has the 0% value as its abscissa. This is explained by the fact that subjects, in the range given (the range of values that presents uncertainty), choose the equal response, for all configurations that make them doubting. Even if the results in both cases are quite right, it is clear that the first case (upper nominal configuration) shows that subjects were closer to the perfection than in the second one. The best proof is the fact that the GRR mean value is more important in the first case than the second one. We remind that in the psychophysical tests, using the JND mean value, the values tend to be less important than the GRR case (between 15 and 25% in a discrimination case). We can see that as a complement of 100, between the mean value of the JND and the GRR.

TEST 2 RESULTS (DISPLACEMENT DISCRIMINATION WITH A CONSTANT FORCE)

There is always two nominal values which correspond to 20mm for the blue curve and 10mm for the red one.

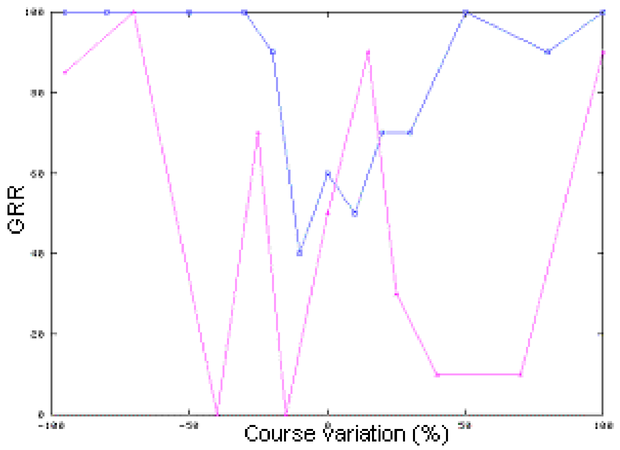

FIGURE. 3
GOOD RESPONSES RATE AS A FUNCTION OF THE COURSE VARIATION (CONSTANT FORCE)

Analysis:

The behaviour of the blue curve is similar to the first test i.e. it presents also a symmetry with respect to the vertical axis with a 0% stroke variation value as abscissa, and a response rate greater than 50% for a displacement variation c, such that c $\in$ [-95, -20]$\cup$[20, 100]%. On the other hand, the behaviour of the red one (lower nominal configuration) has no relation with those of the test1. we can notice that this curve presents many perturbations like for example null response rates for displacement variation c, such that c = {-15, -40}. This is confirmed by the comparison of GRR mean values for both cases. The GRR mean value for smaller nominal configuration cases represents only half the nominal value of the superior nominal configuration case.

Comments:

The most important to notice in this test is that subjects were disturbed in the inferior nominal configuration case. Even if in this case the GRR mean value is still correct, the curve behaviour is uncertain and the difference between both GRR mean values is still important. We can conclude that push buttons with weak strokes can present a riddle for operators.

TEST 3 RESULTS (STROKE DISCRIMINATION WITH A VARIABLE FORCE)

This test is the same as test 2 except that the force is variable.

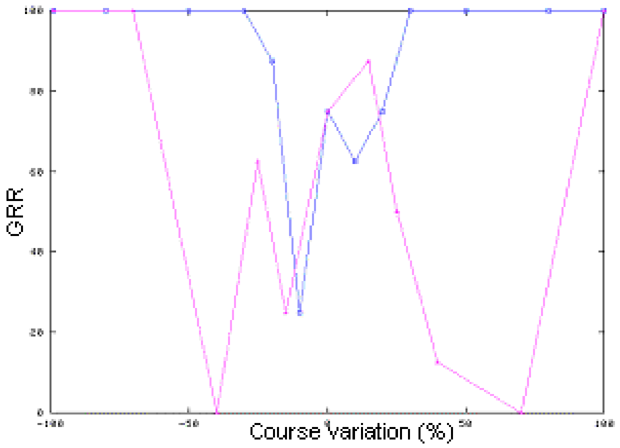

FIGURE. 4
GOOD RESPONSES RATE AS A FUNCTION OF THE COURSE VARIATION (VARIABLE FORCE)

Analysis:

In general, in the case of this test, we can give the same remarks as test 2. The behaviour of the lower or smaller nominal configuration case is still stochastic and GRR mean values very different.

Comments:

Since the force is variable and the results are very similar to the case of a constant force, we can assert that subjects had no difficulties to separate information bind to the displacement and ones bind to the stiffness.

TEST 4 RESULTS (STIFFNESS AND COURSE DISCRIMINATION)

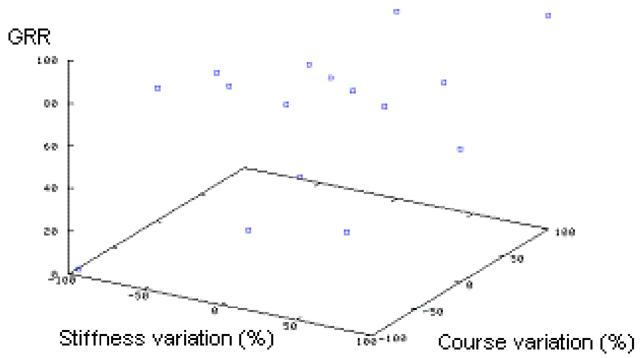

FIGURE. 5
GOOD RESPONSES RATE AS A FUNCTION OF THE COURSE AND STIFFNESS VARIATION.

Figure 5 represents the good responses percentage for a given configuration, which is determined by a stiffness and course variation.

Since a configuration is designed by the variation of two quantities (which represents the horizontal plane in figure 5) and the good responses rate (represented by the vertical axis in the space).

Analysis:

Cases where good responses percentage is less than 50% are 3 among the 15 configurations. In these 3 cases, the course and stiffness variation percentage does not go beyond ± 25%, while in all other cases the good responses rate is raised enough. The GRR mean value is important enough because the test itself is not so easy to support.

Comments:

Except the fact that subjects were good enough, it is important to note that the sensibility of the stiffness variation seems to be more important than the course variation. We can see that for the same variation percentages of the two quantities, the right responses rate is always more important than the stiffness variation case. We can talk in this case about better perception of the caught information of stiffness with respect to the one caught in the course, without having a dominance of stiffness information over the course one.

TEST 5 RESULTS (COURSE DISCRIMINATION WITH A TRANSLATION AXIS DIFFERENT FROM THE Z ONE)

Another case of a 3D representation of the obtained results from the good responses rate, is the one that permits the representation of the good responses rate as a function of the course variation of the button and its position in the scene with respect to the Z axis.

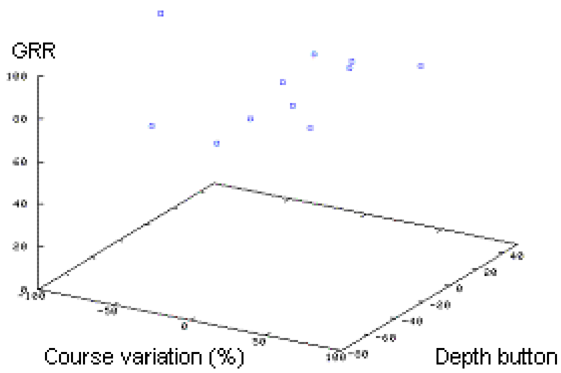

FIGURE. 6
GOOD RESPONSES RATE AS A FUNCTION OF THE COURSE VARIATION AND THE BUTTON POSITIONING WITH RESPECT TO THE Z AXIS IN THE SCENE.

Comments:

We think that a very important parameter, which allowed us to obtain many good responses, is the fact that the button was translated along an axis different from the Z one. This permits to subjects to really perceive the distance made by the button, which is due to the visual feedback.

We can also notice that for the same course variation, we obtain higher rates of good responses, in the case where the button is placed far in the scene than when it is placed close.

TEST 6 RESULTS (INTERMEDIATE POINT POSITIONING BETWEEN TWO COURSES)

Figure 7 represents the subjects' appreciation variation of the modification of the end course extension with respect to, or over the total course. The blue curve is corresponding to a total course value of 20mm, while the red one is corresponding to a total course value of 40mm.

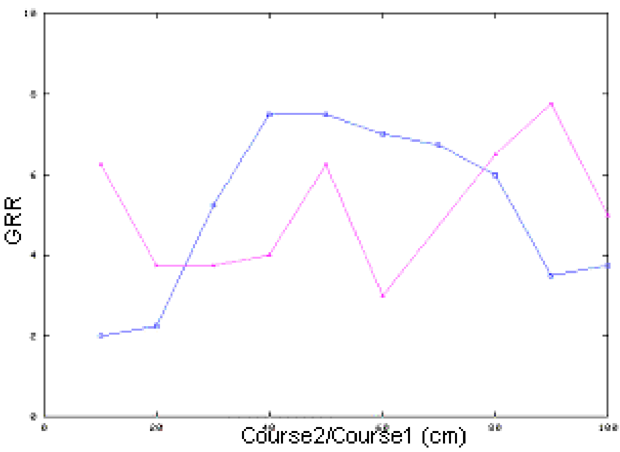

FIGURE. 7
CLICK APPRECIATION (A SCALE FROM 2 TO 10)

Analysis:

In the case of a total course of 20mm, an appreciation greater than 6/10 is noted for an end course extension, noted e, such that e ∈ [40, 70]. However, in the case of a total course of 40mm, the responses are very uncertain. In both cases, the global means of the appreciations are very close to each others and slightly greater than 5/10.

Comments:

We can see that in the case of a weak course (blue curve), the fact that the point separating both courses is placed in a range that encloses the middle value of the total course, can produce pleasant sensations. This range can be large enough without enclosing the whole distance of the total course. In the case of an important total course, case of the red curve, we notice the presence of 3 peaks (appreciable situations).

The first peak constraints the final course extension to be much inferior to the total course.
The second one make the final course to represent half the total course (the separator point in the middle of the total course).

The third one make the position of the separator point in the beginning of the total course, which produces a very extended end course over the total course.

We have seen that these 3 cases correspond to completely different sensations, where the click sensation is highly felt.

TEST 7 RESULTS (BLIND COURSE DISCRIMINATION)

Figure 8 represents the evolution of the good responses rate (percentage) as a function of variations made to a nominal configuration of the course (20mm).

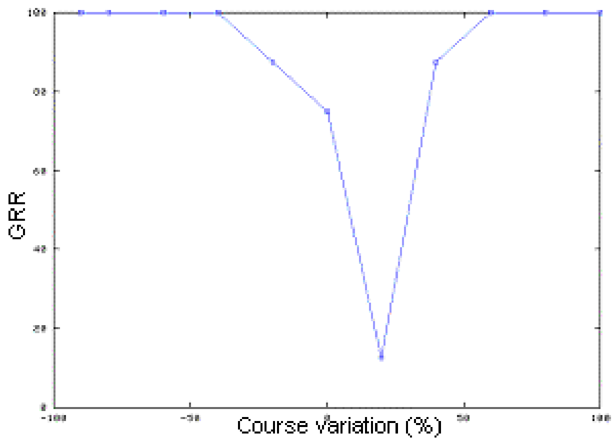

FIGURE. 8
GOOD RESPONSES RATE AS A FUNCTION OF THE COURSE VARIATION (BLIND COURSE)

Analysis:

For a good responses rate greater than 85%, the course variation, noted by c, such that c ∈ [-90, -20]∪[40, 100]%, varies in a large range. For the rest and if we consider that the case where c = 20% is a disturbance, we can see that the responses are so right enough that even the case where c = 0% does not represent at all a peak in this test. All what have been said is reinforced by the mean value, important enough, of the GRR = 87.5.

Comments:

It is clear that this test gives the best results in terms of good responses rate. The elimination of the visual feedback permits to subjects to concentrate themselves on the distance made by the button. We remind that, with respect to results found in tests (1, 2, 3, 4), the judgment on the course is more difficult than the one on the stiffness. We conclude by saying that in the other tests and in case of doubt, subjects sometimes avoided to see the screen of the station. This could explain the results that have been obtained.

CONCLUSION

In this paper, the experiments [1] have led us to the following conclusions:

- For the case where we have a variation of the course of the button, the smaller its nominal value, the more stochastic our results are.
- The perception of the testers is higher when the stiffness is tested.
- It is much more difficult to discriminate the differences between the nominal and the various buttons, when both the course and the stiffness change.
- The lack of visual feedback is a major drawback for the testers, as it is much harder to notice the differences only through force feedback.
- The fatigue of the testers should be taken into consideration, as some of the results towards the end of the test show that their perception is reduced (these results should be considered as perturbations).

A future objective is to integrate the button systems in an existing VR automobile simulator. In that way it will be possible to validate if the force provided by a certain button permits its effective use while driving, which is a critical factor of the efficiency of a control. Such a procedure will give the possibility to predict and correct any shortcomings of a control early in the stage of design, which will help the constructor to save an important amount of time and capital, linked with errors that are detected late in the production chain [4].

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