Application of a Relative Visual Performance Model in a Virtual Reality Immersive System

Benoit Perroud, Stéphane Régnier, Andras Kemeny, Frédéric Mérienne

Abstract—Visual simulation is increasingly taking part in the engineering and styling design of new products, particularly in the automotive industry. As part of an evaluation process of user experience realism in a Virtual Reality system, we focus in this paper on one of the core characteristics of vision: the relationship between contrast and luminance. The experiment aims at validating in VR reaction time predictions given by Rea and Ouellette's model. The subjects have to distinguish, as fast as they can, a target appearing on a uniform background. Our results disclose a major difference in behavior compared to the theoretical predictions. However, there is a statistical correlation between the measured and the theoretical data. The size of the background might be the reason for this difference. We conclude that the Rea and Ouellette's model could be applied in VR if a specific factor was added.

Index Terms—Contrast, Luminance, Visual Performance, Virtual Reality

✦

1 INTRODUCTION

S IMULATION, through the use of simulators and immersive display systems, becomes an increasingly preponderant factor in the development of new products. In the automotive industry, it is largely used for relative and, sometimes, absolute validation of vehicle systems designs, such as Human Machine Interface (HMI) and Advanced Driver Assistance Systems (ADAS), or human factors studies [1]. Manufacturers hence need trustful tools in order to make decisions.

The display part of a simulator must be treated with great care and the measure of its quality appears to be essential (as an example, for driving simulators, 90% of the information used by a driver is considered to be visual, though it is yet to be fully proved numerically [2]). Our goal is to make the simulator achieve one of the five acceptations of realism [3]: the information provided to the sensory system of the body (in our case, the eyes) are to be the same that one could have in a real life situation.

This paper focuses on one of the core characteristics of vision: the relationship between contrast and luminance. These two attributes are closely linked and are key factors in the trustfulness of a display. The aim is to be able to describe how much contrast and luminance one needs in Virtual Reality in order for the visual system to work as it would in real life, as well as to determine what is their relationship and how the human visual system behaves at different levels of contrast and luminance.

B. Perroud is with both the Le2i (FRE 2005) lab, **Arts et Métiers**, CNRS, Univ. Bourgogne Franche-Comté, HeSam, Institut Image 2 rue T. Dumorey 71100 Chalon-sur-Saone France and the VR and Immersive Simulation Center, **Renault**, Guyancourt, France
S. Régnier is with the VR and Immersive Simulation Center, **Renault**, Guyancourt, France
A. Kemeny is with both the Le2i (FRE 2005) lab, **Arts et Métiers**, CNRS, Univ. Bourgogne Franche-Comté, HeSam, Institut Image 2 rue T. Dumorey 71100 Chalon-sur-Saone France and the VR and Immersive Simulation Center, **Renault**, Guyancourt, France
F. Mérienne is with the Le2i (FRE 2005) lab, **Arts et Métiers**, CNRS, Univ. Bourgogne Franche-Comté, HeSam, Institut Image 2 rue T. Dumorey 71100 Chalon-sur-Saone France

2 RELATED WORKS

On the one hand, contrast can be roughly described as a ratio between different luminances. Its behavior is most of the time associated to threshold above which a person is able to distinguish a target in a background and below which the same person cannot distinguish the target. Although the generally accepted threshold value is 1% of the background luminance, there exists numerous methods to mesure the value of the threshold and many applications [4].

On the other hand, luminance is described in photometry as the luminous intensity emerging from a surface and converging to the eye. Based on its value, it can belong to the photopic field ($L < 0.001 \ cd/m^2$), the scotopic field ($L > 10 \ cd/m^2$) or the mesopic field ($0.001 < L < 10 \ cd/m^2$).

Rose [5], in 1948, published one of the first works that tried to evaluate performance on a absolute scale. Rose tied contrast, luminance and size in a single formula (Eq. 1) where α is the size of the object to be seen, L the luminance of the object and C the contrast of the object with respect to the background. k is a constant member that can be computed with other parameters.

$$\alpha \times L \times C^2 = k \qquad (1)$$

While the Rose model gives a very good approximation of a Bayesian ideal observer, it has a limited range of validity. Hence, Burgess [6] revisited it to serve image quality purposes. Progress has been made on the model in limiting the performance by the noise of the input signal.

Though, as it appears that there exists a contrast value beyond which performance diminishes, the single threshold contrast value seems to not be enough. Following this idea, the International Commission for Eclairage (ICE), mostly based on the work of H. R. Blackwell [7], designed a model of visual performance. The approach specifies a level of performance in completing a task based on its lighting parameters such as luminance and contrast. It thus serves to establish task lighting standards. The model first computes a level of visibility at which the task is performed and then

rates the overall performance. The entry parameters of the model are the difficulty of the task, the age of the observer and the lighting parameters. Its range is quite consequent as it takes in a luminance from 1 to $10000 \, cd/m^2$. However, it only works for eccentricities lesser than 3 degrees. One main drawback of the model is that it should not be used in interior lighting as light is then mostly directional and specular.

However, the CIE model is only an enhanced contrast threshold model: suprathreshold values are obtained through multiplying the threshold by a constant (the visibility level). That's why Rea [8], [9] proposed a bit later its own model of visual performance (RVP). Its model provides results similar to other studies measuring suprathreshold behavior. Rea goals were to build a suprathreshold visual performance model that would be independent of task performance and consistent with the literature. His model is based on the compression effect that was theoretized out by Naka and Rushton in 1966 and Lipetz in 1969 as a self-shunting mechanism. The compression effect implies that at some point, despite increasing the magnitude of a stimulus, the sensation magnitude will not increase. The compression effect is described in the following equation (Eq. 2) with R the response, R_{max} the maximal response, I the stimulus intensity, n an exponent and K the stimulus intensity producing half of the maximum response.

$$\frac{R}{R_{max}} = \frac{I^n}{I^n + K^n} \tag{2}$$

In a second time, Rea and Ouellette expanded Rea's RVP model with a reaction time experiment [10]. They built a model that can predict the reaction time to performing a vision task. The difference between reaction times in given conditions of luminance and contrast, and a reference reaction time, can then be linked to a RVP value. Later on, Rea and Ouellette enhanced their model to add the influence of aging [11].

Last but not least, enhancement propositions of Rea's model were made by Kambich [12] in 1991 and by O'donell *et al.* 20 years later [13]. For Kambisch, though the model is a valuable tool based on robust data, the size and contrast treatments have weak theoretical bases. Kambich then replaces the sole contrast measure by three stages modeled on vision models: linear filtering, non-linear filtering and pooling stage. His model does not however consider adaptation luminance. O'donell *et al.*, on their side, showed that the addition of color in the model of RVP can significantly raise the performance level. Luminance and color are both important in the treatment process of the image by the brain. However, the importance of color is related to the amount of contrast: the lower, the more important color is. Under contrast values of 0.2, color can be used to help performance, while for contrast values over 0.6 the sole luminance drives the performance.

In our study, we decided to focus on Rea and Ouellette's model, without taking into account enhancements proposed by Kambich and O'donell *et al.*. The point is to validate the reaction time predictions, through an experimentation, that can be computed through Rea and Ouellette model. The validation or invalidation would allow us to say whether the RVP model is fitted for Virtual Reality or not.

Figure 1. View of the experimental setup. Subjects were seated 2 meters far from the front face of the CAVE-like display system and presented a disc-shaped luminous stimulus (here in black over a (176, 176, 176) light gray background).

3 APPARATUS

To evaluate the validity of Rea's model in Virtual Reality (VR), we came with an experimental protocol somewhat close to his. However, some hypotheses and adaptations were necessary (*see below*).

The experiment took place in a 4 faces CAVE-like display system and involved 32 subjects: 23 males and 9 females between the age of 20 and 27 years (mean = 25, sd = 1.8). The CAVE-like display system specifications are as follow: a width of $3.60m$ for a height of $2.70m$ and a depth of $4.20m$. The resolutions of the faces are $1600 \times 1200 \, px$ for the front and floor faces, and $1920 \times 1200 \, px$ for the side faces. There was one Panasonic WUXGA (85000 lumens) projector per face, equipped with an ET-DLE030 fixed focal length lens each. The projection was direct. The subjects were seated in a car seat and positioned for their eyes to be 2 meters away from the front face (Fig. 1). They were not wearing any 3D-stereoscopic glasses and the experiment was carried out with monoscopic images. They also had the instruction to keep the head still in the head-support and to focus on the location where the targets would appear.

The whole 4 faces were displaying a unique grey color (the background color). No other lights were lit in the room, the CAVE-like display system screens were hence the only source of light. The background color was varying between 5 values during the experiment in order to change the amount of light arriving to the eyes of the subjects. The values and their associated luminance can be found in Tab. 1.

Table 1
Relation between background color and background luminance - Number of trials/contrasts per subject for each background luminance

RGB Code	Luminance	Nbr of trials
(0,0,0)	$0.07 \, cd/m^2$	13
(32,32,32)	$0.41 \, cd/m^2$	22
(80,80,80)	$3.74 \, cd/m^2$	26
(128,128,128)	$11.72 \, cd/m^2$	26
(176,176,176)	$23.18 \, cd/m^2$	20
(255,255,255)	$42.90 \, cd/m^2$	13

A stimulus shaped as a 2cm-wide disk was appearing at random timings at the center of the front face. The subjects

had to press the A button on a Xbox360 controller they held in their hands as soon as they perceived the stimulus. Doing so, we could measure their reaction times. The color of the stimulus was varying over different pre-calculated levels of grey to achieve certain amounts of contrast.

In order to be able to predict what levels of gray should be used to display a specific amount of contrast for a given background luminance, we carried out a preliminary set of measures. First, all screens were lit in a plain level of gray. Varying the level of gray, we measured the luminance emitted. We hence could plot the transfer function of the RGB code toward the luminance ; which equation was found with a least squared regression (Eq. 3). Similarly, on chosen background luminances (those used in the experiment) we displayed the target and made its level of gray vary and took measures of its luminance as well. Another equation, for the luminance of task with respect to its RGB code, was then extracted with a least squared regression (Eq. 4). x represents the RGB code value which is the same for the R, G and B components as we are only working on levels of gray. The Maple software from Maplesoft was used for the regressions. No direct calibration of the other screens was performed, only an indirect one: the side screens were lit only so that their influence was taken into account when calibrating the front screen (on which the whole experiment took place). The measures were made with a Konica-Minolta Chroma Meter CS-100. All measures, and afterwards, the experiment itself, were conducted after a 1 hour warm up of the projectors as recommended by the CIE (IEC 61966-6:2005).

$$L_{bck}(x) = -65.5x^4 + 90.1x^3 + 19.7x^2 - 1.3x + 0.1 \quad (3)$$

$$L_{tgt}(x) = -26.1x^4 + 38.3x^3 + 3.7x^2 - 0.03x + 0.02 \quad (4)$$

The contrast is originally computed in Rea's experiment like in Eq. 5. We make the hypothesis that the adaptation luminance (L_a), which is the total luminance which arrives to the eye, is equal to the the luminance from the screens (background luminance, L_B). In other words, we assume that since the screens are the only source of light in the room, the adaptation luminance is the luminance emerging from the screens.

$$C = \frac{T|L_B - L_T|}{L_a} \quad (5)$$

Rea and Ouellette used a neural filter of transmitance T to pilot their contrast value: they would reduce the perceived contrast by densifying the neural filter in front of the eye. Plus, they used a small light directed toward the eye with a beam splitter to add on command a veiling light to reduce perceived contrast. Since we pilot our contrast directly on the screen by changing the color of the task depending of the background, we did not use any filter or veiling light and can then always set the transmitance value to $T = 1$. Hence, with both hypotheses, we came with our own contrast equation (Eq. 6). Both equations only work when the background is more luminous than the task ($L_B \geq L_T$), allowing to compute contrast values by lower value only. We hence also use a slightly modified version of the equation to compute contrast values by greater value (Eq. 6).

$$C = \frac{|L_B - L_T|}{L_B} \ and \ C = \frac{|L_B - L_T|}{L_T} \quad (6)$$

The subjects were first invited to sit in the car seat and then introduced to their task (stimulus detection and reaction time measurement). The experiment was unfolding as follow: a background luminance was set and the subjects had to wait for 3 to 5 minutes so that their eyes would accommodate to the new luminance. When the subjects felt ready, they could launch the apparitions of the targets by pressing another button on the controller. False-positives were not taken into account (nothing occured if the subjects were to press the button when no target was displayed). When the sequence was launched, targets appeared successively with a random time between each. The target contrast relative to the background were specifically chosen to produce a desired contrast among 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90 and 1. The contrast values were achieved, when possible, by target color brighter and darker than the background. Hence, the number of trial per luminance was different as for some background luminances some contrast values (either by brighter or darker value) were not possible. The order of contrast appearance was randomly sorted for every subject. This helped limit the possible training effect among the subjects. When finishing a sequence at a given background luminance, the background luminance was then changed to another one and the whole process was repeated. Similarly, the order of background luminance was randomly chosen for every subject. The subjects got 6 non-measured trials before the beginning of the experiment to get used to it. They were done at a luminance that would no be used during the normal experiment. This also helped counter the training effect as there was no discovery effect during the recorded parts of the experimentation.

For a better understanding, a flowchart of the unfolding of the experiment can be found in Fig. 2. For each of the 6 background luminances (Tab. 1), there is a different number of displayable contrasts values (Tab. 1).

4 RESULTS

To compare theoretical and measured reaction times, we first computed the predictions of Rea and Ouellette's model. Theses values can be found in Tab. 2. The values out of the range of the model (which predicts that one should not be able to distinguish the target over the background and hence does not provide a reaction time value) are left blank.

Some theoretical values such as $25432 \ ms$ or $10865 \ ms$ of predicted reaction time can seem rather important. Those come from a division in the model where the divider is very close to 0 (at least much closer than in the other cases) and hence the result races up very quickly.

The averaged measured reaction times values of the 32 subjects are listed in Tabs. 3 and 4 with their corresponding standard deviations. Since the population is over 30 subjects, the Pearson standard deviation was used.
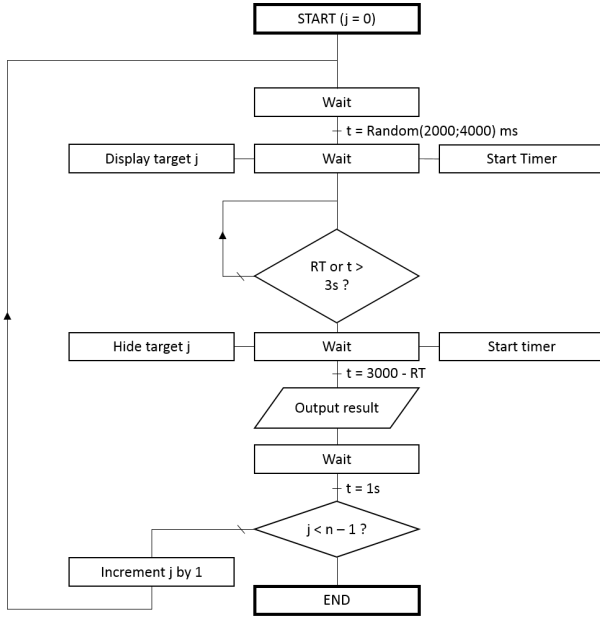
Figure 2. Flowchart of the unfolding of a sequence of targets appearances, for a given background luminance.

Table 2
Theoretical reaction times (in ms) predicted by the Rea and Ouellette model.

C/L	0	32	80	128	176	255
0.05						
0.10						
0.15					10865	3594
0.20			25435	1924	1429	1212
0.25			1686	1041	912	839
0.30			1039	788	725	685
0.40		2663	696	596	568	549
0.50		1272	577	517	499	546
0.60		929	517	473	549	449
0.70		773	481	446	434	425
0.80	4451	684	456	426	416	409
0.90	2448	626	439	412	403	396
1.00	1720	585	425	402	393	387

Measured values range from $371\ ms$ to $670\ ms$ with a mean value (of the means, excluding the diverging value, *see afterwards*) of $437\ ms$ (SD = $53\ ms$) and a mean standard deviation of $96\ ms$ (SD = $82\ ms$). A particular value ($2013\ ms$ for a constrast of 0.05 and a background luminance of $0.41\ cd/m^2$) can be highlighted.

The performance R is defined as the inverse of the reaction time RT: $R = 1/RT$. It is used instead of the reaction time to characterize the performance of a subject. The performance hence increases when the reaction time decreases. The graphs in Figs. 3 and 4 show both theoretical and measured performances in the reaction time experiment. The x-axis represents the different values of contrast, clamped by definition between 0 and 1. The y-axis represents the performance R, inverse of the reaction time (in ms^{-1}). The values of the predicted performance below the threshold are out of the range of the model. They are hence set to 0 which would be equivalent to an infinite reaction time and thus a lack of reaction.

We performed some Pearson's correlation statistical tests on our data to determine whether there is a link between

Table 3
First half of the measured reaction times (in ms) and their respective standard-deviation.

C/L	0	32	80
0.05	465 ± 58	2013 ± 429	670 ± 112
0.10	474 ± 98	663 ± 447	450 ± 86
0.15	474 ± 85	553 ± 286	439 ± 78
0.20	468 ± 67	531 ± 323	418 ± 48
0.25	465 ± 158	479 ± 63	415 ± 68
0.30	475 ± 141	507 ± 215	423 ± 73
0.40	443 ± 74	457 ± 59	451 ± 221
0.50	440 ± 44	461 ± 78	418 ± 71
0.60	440 ± 58	451 ± 66	405 ± 52
0.70	466 ± 94	450 ± 80	416 ± 72
0.80	432 ± 68	443 ± 67	402 ± 46
0.90	464 ± 79	440 ± 61	404 ± 58
1.00	448 ± 152	426 ± 41	403 ± 52

Table 4
Second half of the measured reaction times (in ms) and their respective standard-deviation.

C/L	128	176	255
0.05	572 ± 314	500 ± 290	450 ± 155
0.10	421 ± 66	434 ± 71	406 ± 50
0.15	421 ± 85	434 ± 99	404 ± 48
0.20	422 ± 87	407 ± 75	432 ± 88
0.25	101 ± 50	141 ± 62	398 ± 92
0.30	399 ± 53	412 ± 63	393 ± 72
0.40	400 ± 59	406 ± 63	396 ± 52
0.50	409 ± 62	394 ± 42	415 ± 67
0.60	396 ± 52	403 ± 6	402 ± 81
0.70	394 ± 49	408 ± 57	390 ± 48
0.80	405 ± 80	394 ± 48	398 ± 67
0.90	402 ± 61	400 ± 64	399 ± 77
1.00	401 ± 77	398 ± 64	371 ± 48

the theoretical data and the measured data. The results of the tests are summarized in Tab. 5. It appears that there is a statistical correlation for five of the background luminance setups out of six. Only the darkest setup (with a all black background) presents a p-value greater than the 0.05 threshold.

Table 5
Statistical results of the Pearson's correlation tests.

Background	0	32	80	128	176	255
Qobs	0.853	2.469	2.281	2.514	4.4249	2.715
p-value	0.412	0.031	0.043	0.029	0.001	0.020
rhô	0.249	0.597	0.567	0.604	0.788	0.634
DoF	11	11	11	11	11	11

5 DISCUSSION

The first outcome that strikes is while Rea's model predicts that some task should not be seen (values below the threshold and out of the range of the model), our subjects were able to see all the tasks that were proposed to them, at all the lighting (background luminance and task contrast) conditions.

Secondly, there exists a major difference in behavior between theoretical predictions and subjects measurements. When the performance of the first one, at a given background luminance, increases with the contrast the latter is always sort of constant. The subjects had a similar performance on all the targets. Their reaction times were somewhat identical in however very different lighting conditions.
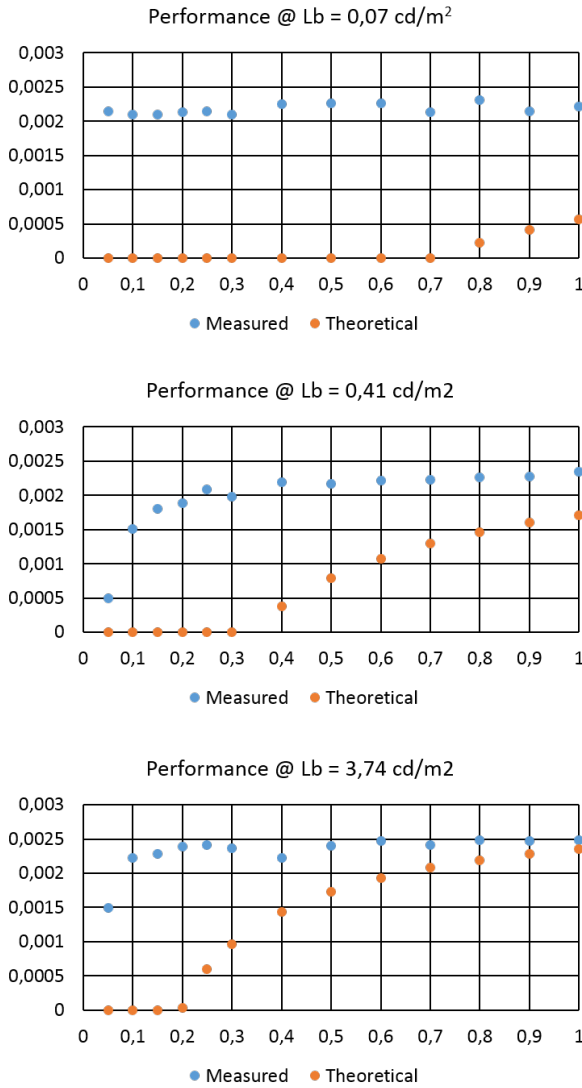
Figure 3. Graph of the predicted performances and the real measured performances in the reaction time task for the three first background luminances.

Figure 4. Graph of the predicted performances and the real measured performances in the reaction time task for the three last background luminances.

Following the predictions of Rea and Ouellette model, our subjects should not have been that potent. They should first not be able to see the target and then, when the contrast increases, become better and better.

At the end of the day, our results do not match at all with the predictions of Rea and Ouellette's model but still converge toward the theoretical values for high contrast conditions. There are fundamental differences that exist between the original experimental setup and ours, that may explain the differences between predictions and measurements.

It appears that only the data of the first condition (grey background 0) are not correlated. All the others sets of data show a strong positive correlation with the theoretical data. These results therefore show that there is a link between the data but without being able to define it. Literature gives us elements to complete the statistical correlations: the size and resulting luminance of the background is supposed to influence the contrast sensitivity.
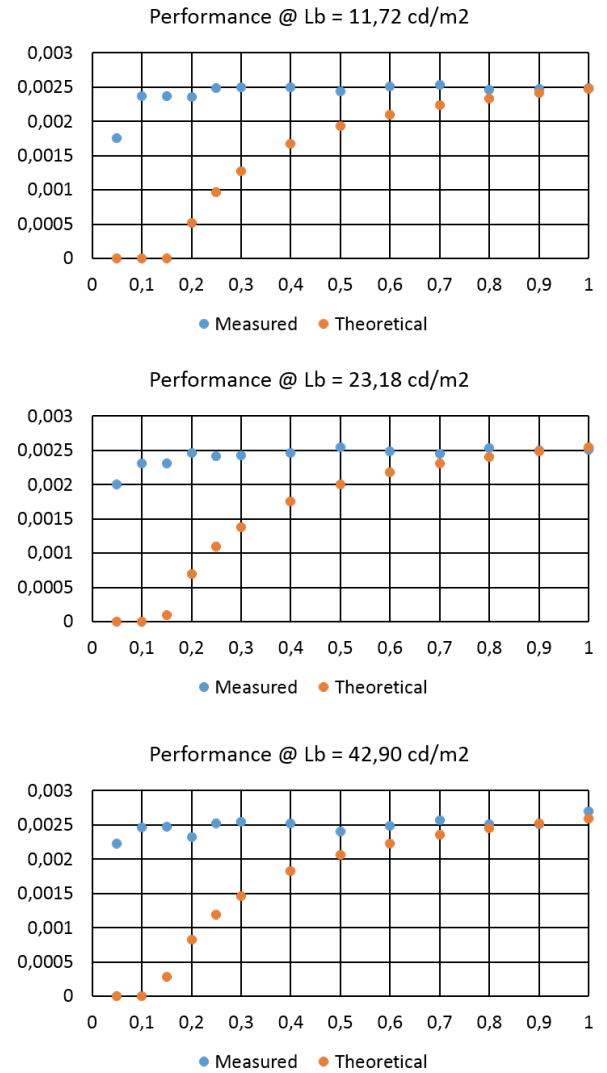
McCann *et al.* [14] have shown that contrast sensitivity is affected by background luminance: it changes significantly with background width and is better with a large uniform background. At the same time, results show that target visibility at the contrast threshold is significantly affected by spatial extent and luminance at the periphery of the field of view. Nevertheless, for high contrast, the influence of the immediate background size fades [15].

Hence, the more light and the more contrast displayed, the more the subjects were helped by the system to perform their task. Two behaviors coexist: on the upper side of the luminous conditions, where the measured values converge toward the theoretical ones, the subjects are correctly following the predictions of the model. On the lower side, when contrast and luminance are low, the subjects should not be performant but their ability to detect the stimulus is boosted by the size of the background, which enhance the subjects' contrast sensitivity, and thus their performance. All in all, whether it is because of the background size or because of the lighting conditions, the subjects are always in a situation

in which they are able to detect the stimuli that are proposed to them.

6 CONCLUSION

The aim of the study was to validate a model describing how much contrast and luminance one needs in Virtual Reality. Models already exists in the literature but none are yet applied to the specific field of Virtual Reality. The goal was to apply one of these models (Rea and Ouellette) in a VR context. An experiment similar to the one in Rea and Ouellette's papers was conducted in a CAVE-like immersive display system. The results show a behaviour that diverges for low contrast and brightness conditions, but converges for high conditions. However, there is a statistical correlation between the measured data and the theoretical data. The size of the background, and by extension the luminance emitted, seems to be the reason for this difference: for low contrast conditions, the larger the background on which the stimulus is displayed, the better the sensitivity of the observer. This effect disappears when the light conditions improve, which explains the convergence of the results on one side (high conditions) and the enhancement of the performance on the other (low conditions). Hence, we conclude that the Rea and Ouellette's model would be valid in Virtual Reality under the condition of an extension and the implementing of an additionnal factor that would take into account the specificities of VR such as the (visual) size of the display. We look forward to implementing such modification factor in future works.

REFERENCES

[1] A. Kemeny, "Driving Simulation for Virtual Testing and Perception Studies," in *Proceedings of the DSC 2009 Europe*, Monaco, 2009.
[2] M. Sivak, "The Information That Drivers See: Is It Indeed 90% Visual ?" *Perception*, vol. 25, no. 9, pp. 1081–1089, 1996. [Online]. Available: http://pec.sagepub.com/lookup/doi/10.1068/p251081
[3] P. Fuchs, G. Moreau, and A. Berthoz, *Le Traité de la Réalité Virtuelle. Volume 1.* Paris: Les Presses de l'École des Mines, 2003, vol. 1.
[4] D. G. Pelli and P. Bex, "Measuring contrast sensitivity," *Vision Research*, vol. 90, pp. 10–14, Sep. 2013. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0042698913001132
[5] A. Rose, "The Sensitivity Performance of the Human Eye on an Absolute Scale*," *Journal of the Optical Society of America*, vol. 38, no. 2, p. 196, Feb. 1948. [Online]. Available: https://www.osapublishing.org/abstract.cfm?URI=josa-38-2-196
[6] A. E. Burgess, "The Rose model, revisited," *Journal of the Optical Society of America*, vol. 16, no. 3, pp. 633–646, 1999.
[7] H. R. Blackwell, *An Analytic model for describing the influence of lighting parameters upon visual performance*, ser. Publication CIE, International Commission on Illumination, Ed. Paris, France: Bureau central de la CIE, 1981, no. no. 19/2.1-19/2.2.
[8] M. S. Rea, "Toward a Model of Visual Performance: Foundations and Data," *Journal of the Illuminating Engineering Society*, vol. 15, no. 2, pp. 41–57, Jul. 1986. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/00994480.1986.10748655
[9] ——, "Toward a Model of Visual Performance: A Review of Methodologies," *Journal of the Illuminating Engineering Society*, vol. 16, no. 1, pp. 128–142, Jan. 1987. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/00994480.1987.10748673
[10] M. S. Rea and M. J. Ouellette, "Visual performance using reaction times," *Lighting Research and Technology*, vol. 20, no. 4, pp. 139–153, Jan. 1988. [Online]. Available: http://lrt.sagepub.com/cgi/doi/10.1177/096032718802000401
[11] ——, "Relative visual performance: A basis for application," *Lighting Research and Technology*, vol. 23, no. 3, pp. 135–144, Sep. 1991. [Online]. Available: http://lrt.sagepub.com/content/23/3/135
[12] D. Kambich, "An Alternative Relative Visual Performance Model," *Journal of the Illuminating Engineering Society*, vol. 20, no. 1, pp. 19–27, Jan. 1991. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/00994480.1991.10748918
[13] B. O'Donell, E. Colombo, and P. Boyce, "Colour information improves relative visual performance," *Lighting Research and Technology*, vol. 43, no. 4, pp. 423–438, Dec. 2011. [Online]. Available: http://lrt.sagepub.com/cgi/doi/10.1177/1477153511412448
[14] J. J. McCann and J. A. Hall, "Effects of average-luminance surrounds on the visibility of sine-wave gratings," *J. Opt. Soc. Am.*, vol. 70, no. 2, pp. 212–219, Feb 1980. [Online]. Available: http://www.osapublishing.org/abstract.cfm?URI=josa-70-2-212
[15] Y. Nakamura and Y. Akashi, "The effect of immediate background size on target detection," *Journal of the Illuminating Engineering Society*, vol. 32, no. 2, pp. 74–87, 2003. [Online]. Available: https://doi.org/10.1080/00994480.2003.10748417

Benoit Perroud is a PhD Student working with both Arts et Métiers ParisTech -inside the Le2i Laboratory- and the Renault's Advanced Driving Simulation and Virtual Reality department. He received a Master Degree in Engineering and a Research Master Degree in Digital Mockup and 3D Visualization from Arts et Métiers ParisTech in 2015. He is interested in realistic vision behavior in Virtual Reality and vision models.

Stéphane Régnier is currently Expert Virtual Mockup for Engineering and Style departments at Renault. He received an engineer's degree from Institut National des Sciences Appliquées in Lyon, in 1990. He has been involved in various visualization software developments, simulation tools, and Virtual Reality, since the early 90's, in various departments at Renault: R&D, Style, Engineering. He has managed several R&D teams, and has a large experience of Virtual Reality, immersive projection systems and 3D visualization solutions.

Andras Kemeny is the Director of the Laboratory of Immersive Visualization, a joint Renault - Arts et Métiers ParisTech research laboratory. He has initiated and directed the development of a driving simulation software package, SCANeR Studio©, a worldwide leader and a major development and assessment driver in the loop (DIL) simulation tool for Automotive Driver Assistance Systems (ADAS), Human Machine Interfaces (HMI), autonomous and connected vehicles, deployed at a large number of automotive OEMs, suppliers and research laboratories. A. Kemeny is also Associate Professor at Arts et Métiers ParisTech and author of more than 150 scientific and technical papers and book chapters as well as several industrial patents and software copyrights.

Frédéric Merienne is currently professor at Arts et Métiers and director of the Image Institute, a research team of the Le2i Laboratory, since 2004. He received his PhD in 1996 at the National Polytechnical Institute of Grenoble (INPG). His research interests are focused on virtual immersion linked with engineering, cultural heritage and health applications. He is the author of many scientific papers in virtual reality and related disciplines. He is involved in different projects with industrial partners, and initiated international collaborative projects in the area of virtual reality with universities in the USA, Australia, Colombia and Malaysia.