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***Abstract*— In this paper we discuss under which conditions standard stereo visual acuity tests can be implemented on 3D TV monitors. In particular, we emphasize the role of environmental lighting conditions, on the measurement of the stereo visual acuity, when using conventional 3D tests, such as Wirt stereotests. We investigate the impact of parameters such as luminance, backlight and contrast when these tests are implemented on 3D TV monitors. We demonstrate that some deviations are observed when modifying the room luminance and the type of displays used (e.g. plasma (PDP) or liquid crystal (LCD) displays). Our measurements carried out on an human sample are supervised by pupil size measurements, using an eyes-tracker, enabling a better interpretation of the results. Finally, we discuss the benefit of using 3D tools to implement stereo visual acuity measurements.**

***Index Terms*— physiological factors, 3D displays, binocular vision, stereopsis, stereotest**

I. Introduction

NUMEROUS investigations have been performed to measure the effects of luminance and contrast on monocular or binocular visual acuity [1]-[3]. In parallel, the recent revival of interest for stereoscopic vision and the related visual discomfort which can result [4]-[5], has focused the attention on stereoscopic vision, justifying a fine analysis of 3D perception dysfunctions, definition of appropriate tests and protocols to measure them as well as recommendations such as ITU-R BT1428 [6]. However, these recommendations do not take enough into account the display type and the environmental lighting conditions which could influence the measurement of the depth perception acuity. The main difference between monocular or binocular tests and depth perception acuity ones is the stimulation of our ability to determine the relative position of objects in space. The retina provides a two-dimensional image. The brain integrates these images from each eye to create a sense of three dimensions. Factors such as excessive binocular parallax (apparent change in the direction of an object due to a change in observational position that provides a new line of sight) and accommodation-convergence conflicts are no longer of minor importance when disparity values surpass one degree limit of visual angle, so that monocular or binocular visual acuity tests are no longer sufficient to understand what occurs when 3D images are displayed. Factors like excessive demand of accommodation-convergence linkage (fast motion in depth), viewed at short distances, and unnatural amounts of blur, impact strongly this perception. In order to adequately characterize such mechanisms, it is needed to assess the stereo visual acuity in a way close to how 3D contents are displayed to observers. Before that, it is necessary, to investigate the impact of environment lighting on these measurements, with respect to the technology used to display the tests. Implementing conventional depth perception tests on TV displays will enable a first scaling of the test to establish a correspondence with conventional tests and then to analyse the impact of different display technology on these measurements due to their different luminance and correlation between contrast, luminance and backlight. This will enable us to establish a link with the above mentioned works and visual acuity dependence to these features, but applied to 3D perception.

II. Radiometry, photometry and lighting sources

When display systems are used to implement acuity tests, radiometric units are used, whereas photometry concerns the eyes' sensitivity (both are concerned here). Different lighting sources would influence the measurements making this point critical because it impacts the mydriasis, thus modifying the visual acuity. Fig. 1 summarizes the different lighting sources, being measured using a photometer (ILM-1335 from ISO-TECH). The most critical parameter is the display choice, being the main source of lighting in the direct sight of light. Two options are possible: plasma display panel (PDP) and liquid crystal display (LCD). Plasma has a very advanced brightness control technology minimizing the visual fatigue [7], is gentle on the eyes and minimizes the chance of visual dysfunctions even after watching a long movie. Its brightness depends on the white area size. In contrast, LCD has a better brightness dynamic, due to the balance between direct luminance and backlight. Table I presents a comparison between these two options.

The contrast corresponds here to the luminance contrast which is the ratio between the higher luminance, L_H and the lower luminance, L_L. This ratio (or the Log of this ratio), often called contrast ratio (CR) is used for electronic visual display devices, like here [10]. This is a dimensionless number, often indicated by adding ":1" to the value of the quotient (e.g. CR = 100:1 with $1 \leq CR < \infty$). A CR = 1 means no contrast. When these displays are used outside a completely dark room, e.g. in the living room (around 100 lx) or in an office (around 300 lx minimum), ambient light is reflected from the display surface, adding to the luminance of the dark state and thus reducing the contrast. This point will be confirmed later on.

TABLE I
MEASURED LUMINANCE AND CONTRAST DYNAMICS COMPARISON BETWEEN PDP AND LCD

LCD LG42LX6500 [8] :		
Max brightness	Max backlight	Contrast = 707:1
Min brightness	Max backlight	Contrast = 237:1
Max Brightness	Min backlight	Contrast = 78:1
Min Brightness	Min backlight	Contrast = 36:1
PDP Panasonic TXP42GT20 [9] :		
Max brightness		Contrast = 187:1
Min brightness		Contrast = 76:1

III. BINOCULAR DEPTH PERCEPTION AND STEREO-ACUITY MEASUREMENTS USING A 3D TV

Eyes are horizontally separated by the inter-pupillar distance (IPD) between 50 to 70 mm. Therefore, both eyes receive slightly different retinal images; stereopsis is a depth perception resulting on binocular retinal disparity between these images (difference in image location on the retina of an object seen by the left and right eyes); the brain fuses left and right images and form retinal disparity, from the distance, the brain extracts depth information. When eyes are focused on a certain point, eyes optical axes converge on that point intersecting at an angle called the parallactic angle. Smallest differences in this angle which can be interpreted as an impression of depth, determine the stereo-acuity. A usual way to measure it, is to use Randot or Wirt stereotests [11]. The Randot test is made up of 10 rectangles of 3 circles from 400" to 20", the Wirt, of 9 rhombs of 4 circles, from 800" to 40" (Fig. 2). One in each pattern is designed to appear standing forward. At a 40 cm distance, the range covered is from 800" to 40" of arc. Turning the Wirt upside down reverses the depth, the test figure receding from the background. For some patients (e.g. with fixation disparity), impressions of depth are affected by the direction in which the depth is presented. The depth is obtained using vectographs (Polaroid recording the stereoscopic pair), requiring polarized passive glasses to present left and right images to the corresponding eye. The idea is to implement this test on a TV, as it has been done for monocular tests [12], but on a TV 3D ready, generating left and right images. The first step consists in scaling the Wirt stereotest, at the correct size, to obtain the same depth, when using a 3D TV, as when using Wirt vectographs. The watching distance for a TV is between 1 and 2 m. Similar tests could be implemented for near vision at 40 cm, with a 3D laptop. For the considered 42' screen diagonal TV, we have chosen 1 m. For such a distance, stereo-acuities are divided by a factor 2.5 as shown Table II. Bold arc values correspond to values not resolved at 1 m, due to the pixel size of the considered display. This limit is here 25" but can be improved by increasing the distance between the observer and the display. Using active glasses (alternated vision by optical shutters) instead of passive ones provides better separation of the video pair than passive [13], limiting possible image ghosting. This solution has been chosen here.

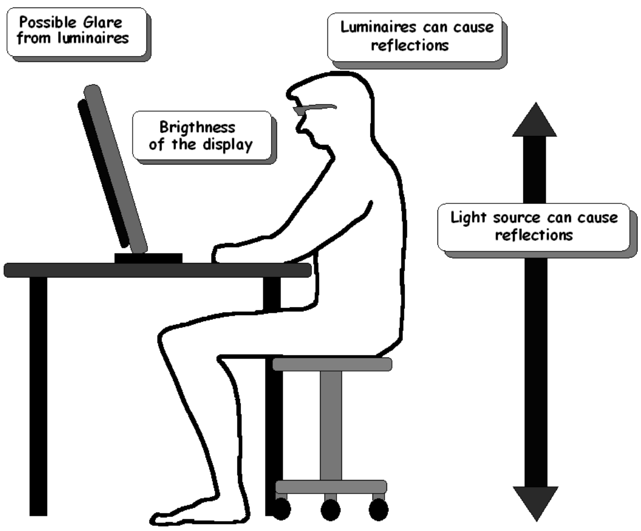

Fig. 1. Different sources of light which could impact the binocular acuity measurements.

TABLE II
STEREO-ACUITY (IN ARC-SEC) FOR TWO OBSERVATION DISTANCES 40 CM AND 1 METER

TEST	Patient at 40 cm	Patient at 1 meter
rhomb n° 1	800	320
rhomb n° 2	400	160
rhomb n° 3	200	80
rhomb n° 4	140	56
rhomb n° 5	100	40
rhomb n° 6	80	32
rhomb n° 7	60	**24**
rhomb n° 8	50	**20**
rhomb n° 9	40	**16**

Because the parallax angle for infinity equals zero, objet (here the grey rings of Fig. 2) appears in relief as far as this angle reaches the stereo-acuity threshold. When this angle is determined, for a given IDP, one can derive the correct observation distance, which is then used to scale the Wirt stereotest size.

IV. Patients and Method

The testing sample has been obtained from 16 different observers (7 females and 9 males) ranging in the age from 22 to 57, (average age 32), serving as subjects. All subjects were informed about the nature of the study prior to experimentation and agreed to participate. Approval for the publication of subject data was obtained from Brest University hospital's institutional review board, according to the tenets of the Declaration of Helsinki. To perform a good calibration of the 3D Wirt tests it is required to operate with normal subjects, with normal acuity and good fusional range. Therefore, each volunteer had healthy eyes, had a good visual acuity (< 0.05 logMAR for a contrast > 100:1), and did not present visual dysfunctions after refractive corrections. They had good image merging capabilities : between 25 to 30 D for the far convergence, 8 to 10 D for the far divergence, and 35 to 40 for the near convergence, 12 to 14 for the near divergence, and they exhibit no objective obstacles to good stereopsis.

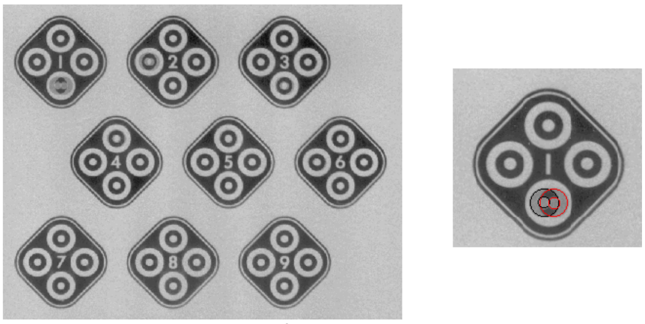

Fig. 2. Wirt stereotest made up of circularly polarized images

To calibrate our experiments a Standard Wirth stereotest has been used in a lighted room, with light sources directed to the test, to provide a better contrast. The test was located 40 cm far from the observer eyes, who is asked to tell which of four circles is highlighted in each rhomb, with a difficulty level increasing at each step. At this distance (corresponding to near vision) it is established that effects such as heterotropia, ocular accommodation asymmetry, oculomotor imbalance, fusional disparity (function of the age and population [11]) can bias the calibration. In addition, TV 3D ready is not appropriate at such a distance, because, first its resolution is not good enough and second the display being an important source of light, at the patient can be dazzled. This is why we decided to locate the patient at 1 m far from the screen. Calibrations performed, the test would be then transferred to a laptop, according to Table III, for near vision measurements. Concerning the test, practice trials are displayed before the testing phase so as to familiarize the observer with the procedure. A 2 minutes break (involving accommodation relaxation by fixing far field) was given every 10 minutes and the whole experiment lasted around less than one hour. The subjects were required to tell whether the randomly displayed depth is observed or not. Since the depth kept changing randomly, the chance of making a correct hit without seeing is very low. Therefore, in order to trigger a stimulus for testing, the subject had to keep staring at the centre fixation point. After a valid response, a neutral scene is displayed for a preset duration. A post-exposure masking stimulus with all the background object and target positions with no depth is presented immediately after stimulation. Subjects were required to indicate the estimated target location, by indicating the number of the Wirt stereotest. Because the visual acuity (and the stereo-acuity) is greatly affected by the level of background luminance [14], we considered two cases: the first where the tests are carried out in a dark room (lighting only due to the TV screen) and the second where the room is lighted by an indirect lighting of 300 lx Ne tubes (corresponding to home lighting conditions and luminance measured on a table in the middle of a room). To take into account factors affecting the dark adaptation, we measured intensity and duration of the pre-adapting light. Finally, we used two different test sets to de-correlate the impact of contrast and luminance on stereo-acuity measurements. First, for a given luminance value, we varied the contrast, and second for a contrast value, we varied the luminance. These tests have been carried out for two different 3D TV types a PDP and a LCD.

They are carried out for lighted and dark room (dark room does not mean scotopic vision < 10-2 cd/m^2, but, in our case, a value close to 1 cd/m^2, due to the display lighting in the darkest case, corresponding to mesopic conditions). We test three screen brightness values, for which we consider 4 different contrasts. For lighted room the adaptation time (for retina complete adaptation) is 5 minutes, for dark room 10 minutes. First we present the Wirt test with nine different depths (800", 400", 200", 100", 70", 50", 40", 30", 20") to determine the threshold value for each observer. Then we present successively 4 Wirt stereotests with each nine rhomb of the same depth. One above the threshold, one at threshold and two below the threshold to check if the value found in the first test is the real observer limit. For instance, if 40" is the threshold, we test : 45", 40", 35", 30", if it is 100" we test : 110", 100", 95", 90". It means 4 contrasts, for 3 background luminances and 5 different stereotests (i.e. 60 patterns in the worst case). Then, the observer rests almost 2 minutes, and we change the screen brightness and increment. The protocol is implemented for both LCD and PDP displays. In order to control the impact of the luminance and contrast variations on the stereo-acuity measurements, we measure the pupil size, using an eye-tracker (Seeing Machines, FaceLab). Small pupil sizes reducing the angular resolution, they impact the stereo-acuity threshold. The Eye tracker has been used particularly in transition areas (between depth perception and no perception). Dedicated software has been developed to determine the raw data of the eye tracker. This application works as a plug-in for the ObserverTM, developed in Java language [15]. Its main task is to recover, display, and store the data logged from the eye tracker. The Eye-tracker provides information such as sight tracking, eyes closing and blinking, PERCLOS (fatigue factor), concentration and jerks and head orientations, and pupil size measurement. This information is particularly interesting close to location where the depth perception is lost.

A. *Experimental results*

Tables III present SVA results obtained from a LCD TV, for various contrast and brightness values. Values are percentage of the population perceiving the displayed depth, with respect to whole, for both lighting conditions. The depth perception depending on different contrast, brightness, and lighting conditions is presented here. The individual features of depth perception of each testers were taken into account. Hence, values from tables allow us to select optimal conditions in which most of all testers (or all testers) can perceive the depth. Because large backlight values result in spatial non homogeneities (impacting the contrast dynamic), we operated with a reduced backlight value. Thus, the LCD contrast dynamic was between 1:1 and 1:100 assuming the contrast variation linear, except at boundaries.

To calibrate the results we compare them with ones obtained with a Wirt stereotest under the same room lighting conditions: 471 cd/m^2 (light reflected by Wirt stereotests is 368 cd/m^2). All subjects tested were able to distinguish the minimum depth of 40”. Wirt stereotests require bright room lighting (because passive). Then, we substituted the PDP to the LCD and carried out the same experiments (Table IV A and B). We observed, in average, better performance with the PDD (probably due to backlight issues). This is noticeable in particular for the smallest depth columns (30” and 25”). In contrast, changes in environmental lighting conditions do not impact significantly the results, both for LCD and PDP.

To confirm our analysis, we measured the pupil size (Table V) in extreme lighting cases (for minimum and maximum brightness). Pupil contour and diameter have been obtained using an Eyes-tracker Facelab 5.0, from Seeing Machines (Fig. 3). As already shown in various papers (e.g. [16]), the pupil size changes with the intensity of the videos displayed on the screen, as well as with the depth fixation due to pupil accommodation. Although the second effect is less significant, it should be considered in our analysis (despite psychological effects are neglected). As reported in [16], it is shown clearly that, if the pupil diameter increases as the depth value increases, the correlation between the pupil size and depth fixation remains weak. Table V provides measurements of the pupil size for a male and a female representative sample, in dark room conditions. We do not notice significant differences between LCD and PDP according to this parameter. Values displayed in Table V give the average pupil sizes measured over the duration of depth fixation sequence. For 0.9 cd/m^2 brightness and a minimum contrast, in the dark case, we observe the mydriasis (around 7 mm) whereas for 62 cd/m^2 brightness and a maximum contrast the myosis is clearly visible (around 4 mm). In contrast, the evolution of the pupil size with the depth value, for a given brightness and contrast, is not in accordance with what was expected from [16]. The pupil size seems to increase as the depth value decreases. An explanation is the relatively small variation in the considered depths, so that the behaviour noticed in [16] is not relevant

TABLE III A
DARK ROOM

Brightness cd/m^2	Contrast	65”	55”	45”	35”	30”	25”
0.9	33:1	0	0	0	0	0	0
1.2	55:1	31	31	13	13	0	0
2	67:1	63	50	25	19	6	0
3.5	100:1	88	75	38	25	25	0
2.3	33:1	56	44	25	25	19	19
9	55:1	88	75	25	19	19	0
13	67:1	88	75	38	19	19	0
23.5	100:1	94	88	50	38	19	0
9	33:1	94	88	31	25	19	19
26.5	55:1	88	88	50	31	31	0
31	67:1	94	88	75	69	31	0
62	100:1	100	94	75	75	25	0

0.9 cd/m^2 measured in front of eyes for the minimum LCD brightness.

TABLE III B
BRIGHT ROOM

Brightness cd/m^2	Contrast	65”	55”	45”	35”	30”	25”
471	33:1	0	0	0	0	0	0
479	55:1	38	19	6	6	0	0
485	67:1	81	44	6	6	6	0
494	100:1	88	81	13	13	13	0
488	33:1	63	50	19	19	13	6
497	55:1	94	94	38	31	13	0
500	67:1	88	88	75	50	25	6
503	100:1	88	88	63	50	19	0
500	33:1	94	94	38	25	25	13
518	55:1	94	94	63	44	31	0
532	67:1	94	94	69	62	38	0
556	100:1	94	94	69	69	31	0

441 cd/m^2 measured in front of eyes for the minimum LCD brightness.

TABLE IV A
DARK ROOM

Brightness cd/m^2	Contrast	65”	55”	45”	35”	30”	25”
0.9	20:1	0	0	0	0	0	0
5	33:1	100	71	42	14	0	14
8	40:1	100	100	42	42	14	0
10	60:1	100	100	71	42	42	0
4	20:1	100	100	42	0	0	0
10	33:1	100	100	42	42	42	0
17	40:1	100	100	42	42	42	14
43	60:1	100	100	57	57	57	14
9	20:1	100	100	57	14	14	0
21	33:1	100	100	57	57	57	29
29	40:1	100	100	57	57	42	14
53	60:1	100	100	57	57	57	14

0.9 cd/m^2 measured in front of eyes for the minimum PDP brightness.

TABLE IV B
BRIGHT ROOM

Brightness cd/m^2	Contrast	65”	55”	45”	35”	30”	25”
441	20:1	0	0	0	0	0	0
447	33:1	86	86	42	29	42	0
468	40:1	100	100	57	42	42	42
491	60:1	100	100	57	57	42	14
447	20:1	100	71	14	0	0	0
462	33:1	100	100	57	57	42	0
488	40:1	100	100	57	57	57	14
497	60:1	100	100	71	57	42	14
471	20:1	100	86	57	14	14	14
500	33:1	100	100	57	57	42	0
503	40:1	100	100	71	71	42	29
509	60:1	100	100	71	71	42	14

441 cd/m^2 measured in front of the eye for minimum PDP brightness.

here. Furthermore, one can notice that these values are at the limit of detection for some patients (see Tables IIIA, IVA). Both considered male and female samples have been able to detect them after a more or less complex oculo-motor exploration. Hence, we suspect the pupil size increase is mainly due to the fixation strength in detecting small depths (at the limit of the SVA) in the picture. This is confirmed by a fine analysis of ocular fixation trajectories with the eyes-tracker (Fig. 4). Fixation points are depicted by large disks (durations > 100 ms). We observed situations where depth perception is not immediate, but obtained after complex eye motion strategies. Our protocol does not take into account this parameter, which probably plays an important role in the SVA threshold determination, as well as in the decision protocol (see [12]).

Fig. 4a shows ocular trajectories, for a 65” depth on each rhomb, but at different locations on the rhomb. This corresponds to a case where all locations have been detected by the observer. Fig. 4b shows ocular trajectories for a 35” depth on each rhomb. Answers show many mistakes (apart for 1 and 4) : left for 1 (left), up for 2 (right), left for 3 (up), down for 4 (down) and down for 5 (up), right for 6 (up), down for 7 (left), left for 8 (right) and left for 9 (up). We have displayed fixation disks, for a 200 ms duration threshold instead of 100ms. Depicted values correspond to the total fixation duration τ spent for each rhomb, involving several fixation points. We notice that rhombs 2, 3, 5 and 6 require intensive research (τ = 6.4, 6.4 , 9.1 , 7.3 s respectively). Fixation is focused, for rhombs 3 and 5, on left-down, whereas the depth (located up) is ignored. Finally, we observed that, over a given fixation duration, perception is no longer possible. The fatigue operates and the observer needs to rest and move the fixation to other parts of the test to recover some depth acuity.

Concerning the display type, we observed a slight difference at the eye-tracker between the PDP and the LCD, in the central part of the screen. Fixation durations are longer in case of LCD, probably due to the backlight which generates contrast non uniformity between the centre and the top and bottom of the screen, which is not the case with PDP. This point emphasizes the critical role of the eyes-tracker in the result interpretation, as well as the importance of taking into account various parameters in the determination of the SVA threshold.

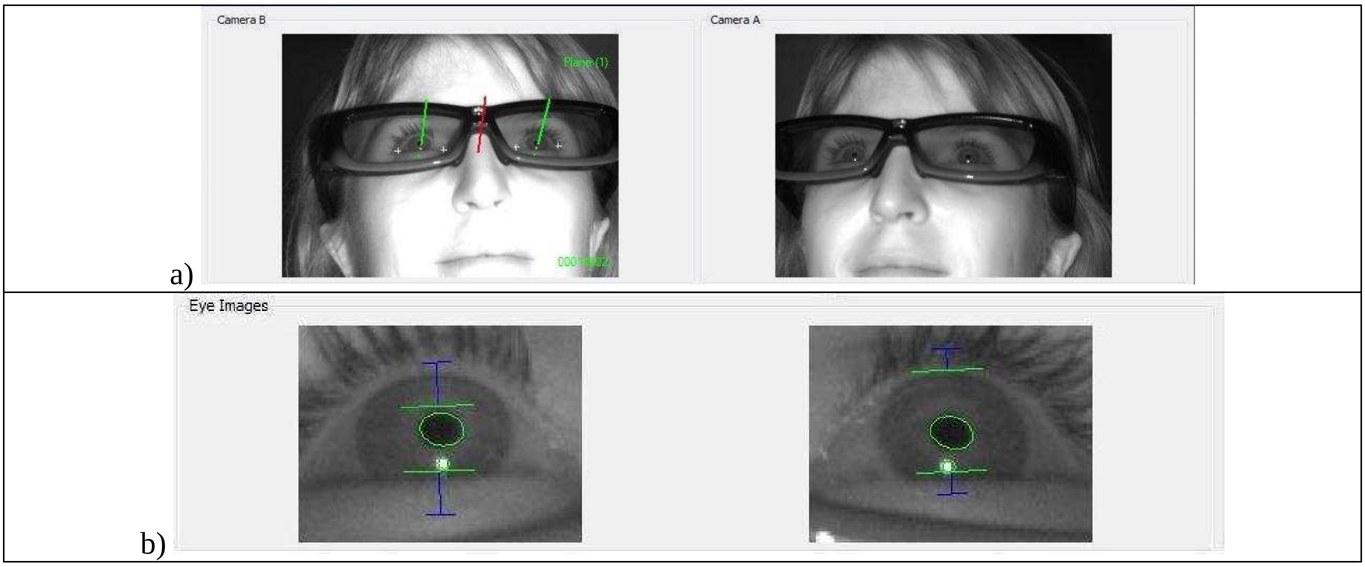

Fig. 3. Pupil contour and diameter extracted by the eyes-tracker

TABLE V

Brightness, cd/m^2	Contrast	65”		55”		45”		35”		30”		25”	
		L	R	L	R	L	R	L	R	L	R	L	R
0.9	**33:1**	5.9	6.1	np		np		np		np		np	
1.2	**55:1**	4.7	5.0	np		np		np		np		np	
31	**67:1**	3.4	3.4	3.7	3.6	3.6	3.6	3.7	3.8	3.8	3.8	3.9	3.9
62	**100:1**	3.5	3.4	3.5	3.5	3.8	3.7	3.9	3.8	4.0	3.9	3.8	3.8
Brightness, cd/m^2	**Contrast**	**65”**		**55”**		**45”**		**35”**		**30”**		**25”**	
		L	R	L	R	L	R	L	R	L	R	L	R
0.9	**33:1**	6.5	6.2	np		np		np		np		np	
1.2	**55:1**	6.1	5.9	np		np		np		np		np	
31	**67:1**	5.5	5.4	5.4	5.3	5.6	5.5	5.7	5.6	5.9	5.7	5.7	5.5
62	**100:1**	4.6	4.5	4.9	4.8	5.0	5.0	5.3	5.2	5.3	5.1	5.2	5.1

Top: a representative male and bottom a representative female sample. Each value is the pupil diameter in mm (np means no perception of depth, the pupil size remains constant).

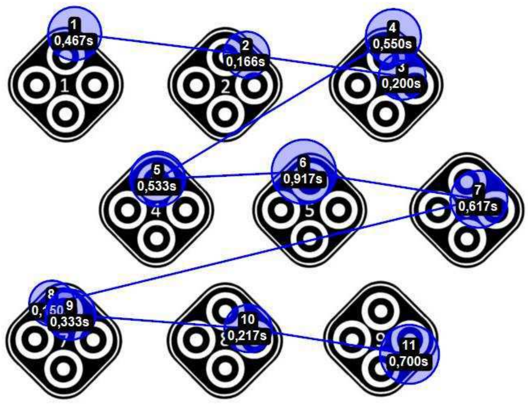

Fig. 4a. Ocular trajectories and fixation durations corresponding to bottom table 6. 65" depths located on top for 1 and 2, right for 3, top for 4 and 5, right for 6, top for 7, right for 8, bottom for 9 (brightness of 62 cd/m^2)

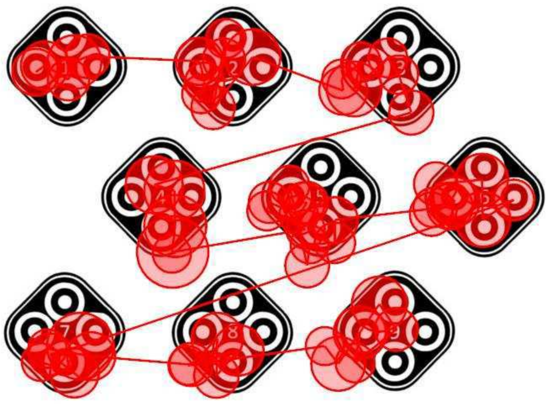

Fig. 4b. Ocular trajectories and total fixation durations τ corresponding to bottom table 6, 35" depths are located on left for 1 (τ = 4.5 s) ,right for 2 (τ = 6.4 s), up for 3 (τ = 6.4 s), down for 4 (τ =4.5 s), up for 5 (τ = 9.1 s) and 6 (τ = 7.3 s), left for 7 (τ = 5.5 s), right for 8 (τ = 4.5 s), up for 9 (τ = 5.5 s), (brightness of 62 cd/m^2)

This use, of course, should be further investigated to clarify, for instance, small pupil size variations.

V. Discussion

Results confirm the impact of brightness and contrast on the stereo visual acuity. SVA improves, when stereotest brightness and contrast increase (for both displays). This is hampered, for large brightness values, by possible dazzling or Modulation Transfer Function (MTF) reduction due to pupil closing [17]. This explains why pupil size measurements should be used to validate the SAV and fix the right operating conditions of the display. Whatever the monitor choice, best results are obtained, for large contrast and brightness values (to prevent mydriasis), with a weak impact of the environmental lighting conditions. It makes a difference with fixed Wirt stereotest measurements, very sensitive to environmental lighting, which can vary substantially and therefore bias the test. With TV 3D ready, lighting is controlled by the display parameters (brightness and contrast). Determintaion of mydriaisis and myoisis is however required to fix the right contrast and brightness operating range, for a given display. About technology, PDP should be preferred to LCD, because providing more homogeneous lighting (confirmed both in the table and in the ocular strategy analysis). This is due to the LCD backlight systems which generate screen brightness and contrast non homogeneities (darker band in the middle of the screen for low brightness). This effect is mitigated with LCD laptops, well suited to implement 3D Wirt tests for near vision. Furthermore, PDP, even in the dark state, maintains a minimum lighting, smoothing the transition between dark and bright screen, during the test. Although these restrictions, we demonstrated the benefit of using a 3D TV to implement SVA tests: first because enabling more reliable and robust analysis, thanks to a better calibration and control of the lighting and contrast parameters, second due to the fact that smaller depths can be displayed randomly, offering more freedom degrees for practitioners to determine the depth sequence displayed to the patient. Another interesting result is the correlation with pupil size and eye motion analysis, providing a consolidation of diagnosis. Such a work could be extended to near vision (40 cm) using a 3D LCD laptop required at such a distance and by adjusting display parameters according to the above analysis. The goal is to demonstrate that 3D tools are very powerful to implement more sophisticated and new tests and protocols to provide efficient, reliable and faster binocular system analysis and diagnosis, but for which SVA implementation appears to be a necessary calibration step.

References

[1] C.A. Johnson, and E.J. Casson, "Effects of luminance, contrast and blur on visual acuity" Optometry and vision science, Vol. 73, N°12, pp. 864-889, 1995.

[2] J. S. Pointer, "Influence of selected variables on monocular, interocular and binocular visual acuity", Optometry and vision sciences, Vol. 85, N°2, pp. 135-142, 2008.

[3] C.H.Y. Chiu, and A.H.S. Chan, "Effect of screen contrast ratio and luminance level on visual lobe shape", Proceedings International Multi-Conference of Engineers and Computer Scientists, Vol. II,IMECS 2008, Hong Kong, pp. 19-21 March, 2008.

[4] M.T.M. Lambooija, W. A. Ijsselsteijna and, I. Heynderickx, "Visual Discomfort in Stereoscopic Displays: A Review", Proceedings of SPIE, Vol. 6490, Issue: 1584, pp. 64900I-6490013, 2007.

[5] T. Shibata, J. Kim, D.M. Hoffman, M. S. Banks, "The zone of comfort: predicting visual discomfort with stereo displays", Journal of Vision, Vol. 11, pp. 1-29, 2011.

[6] Recommendation ITU-R BT.1438, "Subjective assessment of stereoscopic television pictures", 2000

[7] L. M. J. Meesters, W. A. IJsselsteijn, and P. J. H. Seuntiens, "A survey of perceptual evaluations and requirements of three-dimensional TV", IEEE Transactions on Circuits and Systems for Video Technology, Vol. 14, pp. 381-391, 2004.

[8] LG 3D TV specifications [online]. Available: http://www.lg.com/fr/tv-audio-video/televiseurs/tv-3d/LG-42LX6500.jsp

[9] Panasonic plasma 3D TV specifications [online]. Available: http://panasonic.net/avc/viera/eu2010/product/gt_plasma_spec.html

[10] J. Chen, W. Cranton and M. Fihn, "Handbook of Visual Display Technology", Springer Verlag, 2000 pages, 2011.

[11] A.G. Bennett, P. B. Rabbetts, "Clinical visual optics", Elsevier, Health Sciences, 451 pages, 1998.

[12] R.C.L. Lenne, A.J. Vingrys, and G. Smith, "Automated visual acuity testing", Clin. Exp. Optcom, Vol. 77, pp. 190-195, 2007.

[13] J.L de Bougrenet, A. Srivastava, L. Dupont, “Liquid crystal actives glasses for 3-D cinema” special issue IEEE 3D display and visualization, Vol. 6, pp. 522-530, 2010.
[14] J. V. Lovasik, and M. Szymkiw, “Effects of aniseikonia, anisometropia, accommodation, retinal illuminance, and pupil size on stereopsis”, Investigative Ophtalmology and visual science, Vol. 26, pp. 741-750, 1985.
[15] J.M. Diverrez, G. Coppin, D. Iorgovan**, “**Development of a procedure to examine the behavioural patterns relating to the perception of a virtual 3D image” Proc. Measuring Behaviour, Eindhoven, August 24-27, pp. 212-214, 2010.
[16] E.C. Lee, J.W. Lee, and K.R Park, “Experimental investigations of pupil accommodation factors”, IOVS, vol. 52 no. 9 pp. 6478-6485, 2011.
[17] F. W. Campbell, and R.W. Gubisch, “Optical quality of human eye’, Journal of Physiology, Vol. 186, pp. 558, 1966.