Repeated mobility testing for later artificial visual function evaluation

To cite this article: M Velikay-Parel et al 2007 J. Neural Eng. 4 S102

View the article online for updates and enhancements.

Related content
- Real and virtual mobility performance in simulated prosthetic vision
  Gislin Dagnelie, Pearse Keane, Venkata Narla et al.
- Is acuity enough?
  Bernard P Lepri
- Wide-field retinal prosthesis
  Hossein Ameri, Tanapat Ratanapakorn, Stefan Ufer et al.

Recent citations
- Developing a Very Low Vision Orientation and Mobility Test Battery (O&M- VLV)
  Robert P. Finger et al.
- Sehprothesen
  P. Walter
- Sehprothesen
  P. Walter
Repeated mobility testing for later artificial visual function evaluation

M Velikay-Parel\textsuperscript{1}, D Ivastinovic\textsuperscript{1}, M Koch\textsuperscript{1}, R Hornig\textsuperscript{2}, G Dagnelie\textsuperscript{3}, G Richard\textsuperscript{4} and A Langmann\textsuperscript{1}

\textsuperscript{1} Department of Ophthalmology, Medical University of Graz, Auenbruggerplatz 4, 8036 Graz, Austria
\textsuperscript{2} Intelligent Medical Implants GmbH, Bonn, Germany
\textsuperscript{3} Wilmer Eye Institute at the Johns Hopkins University, Baltimore, MD, USA
\textsuperscript{4} Department of Ophthalmology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

E-mail: michaela.velikayparel@meduni-graz.at

Received 13 September 2006
Accepted for publication 25 January 2007
Published 26 February 2007
Online at stacks.iop.org/JNE/4/S102

Abstract
The study investigates the utility of a newly designed mobility test for repeated testing of visual function in patients with severe visual impairment and future application in evaluating functional progress in patients with artificial vision. Ten subjects divided into three groups based on visual acuity (VA) ranging from light perception to 20/200 and reduced visual field (VF) were included in the study. The mobility test consisted of using a set of four different but structurally similar and relatively short mazes having a constant number of obstacles of various sizes. The subjects, divided into three groups by acuity, passed through each course several times. In general, the patients with better VA had a larger extent of VF. Average speed and number of contacts were recorded as measures of performance. The average passing times of the groups through the courses were significantly different ($p = 0.03$), which was influenced by VA and VF. There was no significant difference in average number of contacts between the groups ($p = 0.15$). The mobility test proved to be appropriate for gaining statistically relevant results in repeated individual testing of patients with severe vision impairment. Results show promise for use this mobility test as a tool for assessing visual function of patients undergoing implantation of a visual prosthesis for artificial vision.

1. Introduction
Since the first acute electrical retinal stimulation of blind patients with retinitis pigmentosa (RP) in 1996 [1] several research groups have been developing visual prosthesis for the blind [1–9]. However, none of the approaches to restore vision can replace the physiological function of the photoreceptors. Since the picture given by retinal devices will be unfamiliar to implanted patients, it is a major point of interest how they will adapt to the artificial stimulus. It is assumed that patients will gradually become accustomed to the unfamiliar visual input, and that the retinal implant will ultimately improve the patient’s quality of life. One important component of daily life that is related to visual function is the patient’s mobility. However, in order to use the mobility performance as a measure of visual function, a mobility test, which is applicable for repeated testing, is needed so that patient’s progress can be monitored. The mobility tests developed to date by other researchers are either not amenable to repeated testing because they are too long and require large amounts of space [10–19] or are designed to test subjects whose vision is substantially better than what is anticipated of subjects at the early phase of retinal implants where the assumed visual acuity will still be within the profound visual impairment range with a visual field (VF) of approximately $20^\circ$.

Therefore, a new mobility test has been designed and is described herein. It should be applicable for repeated testing of patients with a retinal prosthesis. Unlike an acuity test, performance improvements are expected in repeated mobility testing due to the subject’s gaining knowledge about the nature of the task. In order for repeated mobility testing to be useful in this regard, it is necessary to develop a test methodology where learning effects rapidly reach an asymptote or occur in a consistent and understandable manner. The approach
Repeated mobility testing for later artificial visual function evaluation

Table 1. Characteristics of the ten subjects.

<table>
<thead>
<tr>
<th>Initials</th>
<th>Age</th>
<th>Group</th>
<th>Diagnosis</th>
<th>Visual acuity&lt;sup&gt;a&lt;/sup&gt;</th>
<th>LogMAR</th>
<th>VF&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>71</td>
<td>1</td>
<td>Retinitis pigmentosa</td>
<td>Light perception</td>
<td>5°</td>
<td></td>
</tr>
<tr>
<td>KP</td>
<td>67</td>
<td>1</td>
<td>Retinitis pigmentosa</td>
<td>Light perception</td>
<td>10°</td>
<td></td>
</tr>
<tr>
<td>BL</td>
<td>40</td>
<td>1</td>
<td>Retinitis pigmentosa</td>
<td>Hand motion</td>
<td>5°</td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>42</td>
<td>1</td>
<td>Retinitis pigmentosa</td>
<td>Hand motion</td>
<td>5°</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>47</td>
<td>2</td>
<td>Usher syndrome</td>
<td>5/200</td>
<td>1.6</td>
<td>5°</td>
</tr>
<tr>
<td>ES</td>
<td>65</td>
<td>2</td>
<td>Usher syndrome</td>
<td>5/200</td>
<td>1.6</td>
<td>5°</td>
</tr>
<tr>
<td>RM</td>
<td>23</td>
<td>2</td>
<td>Retinitis pigmentosa</td>
<td>5/200</td>
<td>1.6</td>
<td>60°</td>
</tr>
<tr>
<td>EL</td>
<td>44</td>
<td>3</td>
<td>Usher syndrome</td>
<td>20/200</td>
<td>1.0</td>
<td>50°</td>
</tr>
<tr>
<td>ZM</td>
<td>13</td>
<td>3</td>
<td>Retinitis pigmentosa</td>
<td>20/200</td>
<td>1.0</td>
<td>15°</td>
</tr>
<tr>
<td>RB</td>
<td>41</td>
<td>3</td>
<td>Atrophy of the optic nerve</td>
<td>20/200</td>
<td>1.0</td>
<td>30°</td>
</tr>
</tbody>
</table>

<sup>a</sup> Snellen charts.

<sup>b</sup> Visual field.

used in this study to address these issues was to develop a set of mobility courses that were structurally similar. They had the same length and width, and contained the same number and types of obstacles and barriers. The hypothesis was that persons with RP will learn the task in a relatively short number of passes and this will be evidenced by a performance plateau. If this occurs, then repeated testing of individuals after they receive retinal implants could be employed to assess their ability to use and adapt to the unfamiliar visual input. It was therefore the aim of this study to evaluate the utility of the newly designed mobility test for repeated visual function testing of patients with severe visual impairment for application in artificial vision assessment.

2. Methods

2.1. Subjects

Informed consent was obtained from all subjects according to the Declaration of Helsinki. The study protocol was approved by the ethics committee of the Medical University Graz. Ten subjects selected from the database of the University Eye Hospital of Graz, Austria, were included in the study. The inclusion criteria were visual acuity (VA) ranging from light perception to 20/200 and reduced visual field (VF), and capability of maintaining a normal walking speed when guided by a healthy person. Nine of the ten subjects had confirmed diagnosis of RP and one patient had an atrophy of the optic nerve due to glaucoma. Three of the nine RP patients had Usher syndrome. The age of patients ranged from 13 to 71 years, with a mean of 45.3 years. Seven patients were female and three were male. Three groups were created based on VA: group 1 consisted of four subjects with the lowest VA of light perception or hand motion measured in ambient light, group 2 consisted of three subjects with VA of 5/200 and group 3 consisted of three subjects with the highest VA of 20/200 (table 1). The VA and the VF were determined separately for each eye. In all subjects the eye with the better VA had the larger VF and is listed in table 1. In group 1 the VA was tested in ambient light, in group 2 with Snellen charts in a distance of 5 ft and in group 3 in a distance of 20 ft. The diameter of VF was determined with Goldmann perimeter in all groups and documented in degrees. In all subjects the VF was localized centrally and symmetrically. VFs greater than 30° extended more infero-temporal, and the largest extent is listed.

2.2. Mobility assessment

Indoor courses with ten obstacles were created. The courses were 11.2 m long and 2.8 m wide. This width was chosen because this was often found in larger corridors. The walls were mat white and the floor had a light shade of grey. All corners were highlighted with black tape. The constant non-glare, uniform illumination was approximately 850 lux. Mobile white screens of 1.4 m width were used to create four different maze patterns (figure 1). Eleven obstacles were positioned on the floor at defined places in each course. Ten obstacles were made of single-ply board covered with black non-reflecting paper and had a width and a depth of 30 cm. The height, however, differed: two of the ten obstacles were at knee-level (30 cm), two at hip-level (90 cm), three at shoulder-level and three at eye-level (130 cm and 150 cm, respectively). A wooden white step (height-width-depth, 15-60-40 cm) with edges marked with a black tape was used in every course.

Each subject walked through the courses with instructions to proceed as fast as possible while avoiding contacts with walls and obstacles, and was observed by an assistant walking directly behind them during every pass. The order in which the courses shown in figure 1 were passed through was randomly assigned for all subjects so that when, for example, course 1 is referred to it is not to a specific course, just to the first
course subjects walked through. To familiarize the subjects with the task, they repeated the first course six times, and after this their passing time had asymptoted. The following three courses were passed four times each. Total time and number of contacts were measured for each pass.

2.3. Data analysis

Data analysis was performed using SPSS 14.0 for Windows. The Kolmogorov–Smirnov test was used to ensure that the measures did not significantly differ from normal distribution. The time did not significantly differ from the normal distribution ($z = 1.198, p = 0.13$) so that parametric tests were used to assess if the groups differ from each other and specifically which groups differ from each other (one-way analysis of variance (ANOVA) and Bonferroni post-hoc test). Analysis of covariance (ANCOVA) was used to determine if the VA or the VF significantly influenced the passing time. The contacts were non-normally distributed ($z = 1.584, p = 0.013$) so that the difference between the groups for contacts was calculated by a non-parametric test (Kruskal-Wallis one-way ANOVA). Correlations were performed by Spearman correlation. Differences between the courses within the groups were calculated with a paired-samples $t$-test. A $p < 0.05$ was used to define the statistical significance.

3. Results

VA was positively associated with average passing time such that subjects with higher acuities generally had shorter passing times ($r = -0.701, p < 0.01$). This was reflected in the one-way ANOVA which indicated there was a significant effect of group on passing time ($F = 5.687, p = 0.03$), although between the groups a significant difference was found only between groups 1 and 3 (Bonferroni post-hoc test, $p = 0.04$). The correlation between the VF and passing time ($r = -0.778, p < 0.01$) indicates that larger VF positively influence the passing time and to a minor extent the number of contacts ($r = -0.568, p < 0.01$). However, when using ANCOVA neither the VA nor the VF had a significant effect on the passing time ($VA: p = 0.08; VF: p = 0.23$), which can be explained by the greater variance of the VF and the limited number of subjects. The difference in contacts between groups was not statistically significant (Kruskal-Wallis one-way ANOVA, $\chi^2 = 3.8, p = 0.15$) but the passing time, however, correlated with the number of contacts ($r = 0.855, p = 0.02$, figure 2).

Noticeable individual differences of average passing time were also observed between patients within the various groups. Most of the patients’ differences were statistically significant: in group 1 significant inter-individual differences could be found in three subjects, in group 2 and group 3 in two subjects each (Bonferroni post-hoc test, $p < 0.01$). The inter-individual differences between patients within the various groups were also shown when comparing the number of contacts (Kruskal-Wallis one-way ANOVA, group 1: $\chi^2 = 42.98, p < 0.01$; group 2: $\chi^2 = 43.83, p < 0.01$; group 3: $\chi^2 = 34.642, p < 0.01$) and between the patients with the VF of 5° ($n = 5$, one-way ANOVA, $F = 29.746, p < 0.01$).

As illustrated in figure 3, when subjects encountered a new course, the average passing time for each group increased from the last run of the known course to the first run of the new course.

Comparing solely the average passing time of the first runs of the courses, it decreased from one to the other throughout the whole test (figure 4).
Repeated mobility testing for later artificial visual function evaluation

Table 2. General data collection.

<table>
<thead>
<tr>
<th>Group</th>
<th>Time (SD)</th>
<th>Contacts (SD)</th>
<th>Course 1</th>
<th>Course 2</th>
<th>Course 3</th>
<th>Course 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.3 (17.6)</td>
<td>7.3 (2.7)</td>
<td>64.2</td>
<td>51.8</td>
<td>53.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>31.9 (18.5)</td>
<td>4.8 (2.8)</td>
<td>35.4</td>
<td>27.7</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>21.7 (10.5)</td>
<td>2 (2.2)</td>
<td>26.2</td>
<td>18.9</td>
<td>19.8</td>
<td></td>
</tr>
</tbody>
</table>

a Average passing time in seconds of all courses.
b Average number of contacts of all courses.
SD: standard deviation.

The learning process varied within the groups: by comparing the increase of speed of each course within one group, we found that group 3 had a significant learning from the first to the second course, whereas the learning process reached a plateau in group 1 and group 2 at the third course (paired-samples t-test, group 1: $T = 2.651, p = 0.033$; group 2: $T = 4.783, p < 0.01$; group 3: $T = 3.824, p = 0.031$).

4. Discussion

The results demonstrate that the newly developed mobility test is applicable for repeated testing for patients with severe visual impairment and indicates the usefulness for future artificial vision training and assessment. The subjects learned the task in a relatively short number of trials, and results showed the ability of the test to discriminate between the various levels of visual impairment based on the assigned groups.

Comparisons to the literature are difficult since the mobility courses used to date have the disadvantages of requiring a great deal of time and require a large amount of space [10–19]. They are therefore not amenable for repeated testing. Furthermore, the tests were designed to compare large groups of visual impaired patients with various diseases.

The average passing time of the groups increased at the last course, suggesting that they had achieved peak performance (table 2 and figure 5). Additionally the end of the learning curve for groups 1 and 3 is also demonstrated in table 2, where the time even slightly increased at the last course, indicating that they had passed their concentration peak.

Figure 4. Decrease of average passing time of the first runs between the courses. The four columns represent the four courses.

Figure 5. The percentage of the average passing time of each course of group 1 (A), group 2 (B) and group 3 (C). Course 1 was chosen to be the reference value of 100%.
and most important, the range of VA tested, was substantially better than the very low vision range of patients who are likely to require and receive a retinal implant for artificial vision. It is expected that the patients with the first retinal prostheses will increase in visual acuity and will progress from blind or nearly blind to an artificial vision in the very low vision range. Another difference is that these test courses were passed only once [11] or twice [10, 14, 17, 20, 22] whereas individuals in this study passed 18 runs and thereby addressed issues of establishing a learning curve. Our mobility test is characterized by the shortness of its courses, which enables repeated measurements within a reasonable time frame. The size of the test allowed development of a set of four different courses, similar in structure and obstacles but not identical.

Unlike in other studies, the subjects’ mean age of 45.3 years was considerably lower, and all were capable of maintaining guided regular walking speed. The variable of preferred walking speed in a non-obstructed environment which has been measured in other studies [11, 23] is not relevant in this mobility test due to baseline measurements and subsequent assessments under the standardized laboratory conditions.

In agreement with observations reported in the literature the average walking speed and number of contacts with obstacles in this study were influenced by the VA and VF [10, 11, 14, 18]. In general the passing time and the number of contacts negatively correlated with the VF. Therefore it can be expected that blind patients will primarily improve their performance after implantation for both reasons the visual improvement and the improvement of the VF. In the later course further increases in performance will most likely display the increase in VA since the VF remains the same.

Generally, individual variances in average walking speed due to mobility training and to different approaches in dealing with obstacles influence the average walking speed as well as the number of contacts. These psychological variables have been assumed to influence the mobility performance [13, 24] since contrast sensitivity, VF, and spatial resolution does not explain all differences. In this study, highly significant individual differences of average walking speed within most subjects of all groups were found. This aspect demonstrates the need of repeated testing for the task performance measures to accurately assess individual progress in artificial vision. However, despite the small number of patients and individual variables, the mobility test of this study demonstrated that it is possible to differentiate performance with respect to VA and VF.

In repeated mobility testing it can be expected that subjects will experience a learning process when passing the course several times. Hassan et al [11] already confirmed that the subjects were significantly slower at the first trial compared with the three following trials, measuring the preferred average walking speed in a normal, non-obstructed environment. Cha et al [25] tested healthy volunteers by reducing their vision by a pixelized vision simulator. He pointed out that learning played an important role in their mobility skills where his volunteers passed the course 50 times.

This learning effect was one of the major points of interest in this study. In order for repeated mobility testing to be useful for assessing progress, it is necessary that the learning effect reaches an asymptote.

Results from this study indicated that the end of the learning curve was reached in each group. We observed that the learning effect differed in groups 1 and 2 from group 3 (highest VA and largest VF). Comparing the average passing times of each course, group 3 had a significant learning effect from the first to the second course whereas the learning process reaches the asymptote in groups 1 and 2 at the third course (figure 5). It is reasonable to assume that the difference in learning of group 3 is due to the reduced challenge of the test when given to persons with better VA and VF. Due to the synergetic effect of VA and VF in our subjects we cannot differentiate the influence of single parameters to the learning effect.

Furthermore whenever our subjects encountered a new course, the average passing time, as expected, increased from the last run of the known course to the new course (figure 3). Comparing solely the average passing time of the first runs of the test, it decreased from one course to the next throughout the whole test displaying the learning effect and the rapid adjustment of the subjects to similar situations (figure 4).

Better VA, VF and the learning effect reduce the average passing time. We therefore addressed the question if the learning effect overrules the differences in patients with very low vision in group 1 and 2. Although not an original objective of our study, we hypothetically compared the course with the maximum speed of group 1 (last three runs of course 3, where they had the maximum learning effect) with the course with the lowest speed of group 2 (last three runs of course 1, where they had the lowest learning effect), and still found significant differences. It indicates that learning effect will not outweigh the differences in average passing time due to the visual function. In other words, even if subjects know the mobility course it can be assumed that the visual improvement is displayed by the test in patients with very low vision.

In future, the test will be reapplied in constant time intervals after implantation. Further studies are needed to gain knowledge of how well the learning effect is retained over time. We assume that the learning experience will fade when the test is not reapplied. Therefore the time frame for retesting after implantation is essential and has to be set accordingly to obtain accurate results.

In summary, the relatively short mobility test proved sufficient for significantly differentiating subjects with respect to VA levels during repeated testing. The simplicity of the course allowed repeated measurements of subjects with severe vision loss and demonstrated that the end of the learning curve was reached within a reasonable time, and the learning aspect is unlikely to confound assessment. The mobility test therefore has the potential to demonstrate an individual’s progress in visual function after implantation of a visual prosthesis.

Acknowledgments

This study was supported by European Union Grant, number 001837. The authors want to thank Alexander Kramer-
Drauberg, MD, Monika Mayer, MD, Dietmar Mattes, MD, for their support.

References


