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Tracking rehabilitative progress with Fitts and starts

Performance measures in a tablet game for hemi-spatial neglect patients.

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***Abstract*— We designed a tablet game to diagnose, train, and assess the rehabilitative progress of hemi-spatial neglect patients. We found that a set of parameters from fitting Fitts' law to hit delays in a whack-a-mole game can be used to identify neglect patients due to the asymmetry between performance on the left and right hand sides of the screen. Performance improvements were evident in in-game metrics as well as to the patients through summary screens.**

Keywords- neglect; self-rehabilitation; Fitts' law; game

I. Introduction

Self-rehabilitation initiatives place emphasis on the growing responsibility that patients and post-rehabilitation patients have for improving their own well-being and progress. Stroke rehabilitation is a lengthy process and the care is expensive. However, it leaves time for patients to improve their situation on their own time even while in rehabilitation centers. Games are now being sought as a means to tap into the intrinsic motivation they promote and research investigates to what degree, for example, causal games train cognitive abilities [1]. We believe that purpose-built games that provide more feedback and are simple for patients to understand are better suited for rehabilitation. However, it is not clear how far we can use measures based on in-game data logging to infer the degree of impairments and to track rehabilitative progress. In this paper we focus on the design, evaluation, and modeling of player data of a tablet based game for the rehabilitation of hemi-spatial neglect patients – specifically for visual restoration therapy and whose interactions can be used as measures to track progress. Our results show that Fitts' law, in addition to the human processor model and game metrics, can provide insights into patients' visual neglect and their rehabilitation progress.

II. Background

Hemi-spatial neglect is a disorder in which people, despite functioning eyes, have a deficit attending to the left hand side of their visual field, often due to right hemisphere lesions. Proponents of visual restoration therapy (VRT) have provided evidence that patients can restore their visual field by being exposed to stimuli at the border of the visual field [2]. A number of methods have been used to diagnose and quantify visual neglect. They include, for example, copying pictures with pen and paper, striking off each dot in a dotted letter, judging which of two bars (left/right) appears first [3], and bisecting lines. Neglect patients who fail to copy the left part of a depicted object only strike off the right hand part or make substantial rightward errors when bisecting lines. Mattingley *et al.* found neglect patients exhibit motor neglect – a delay in initiating movements towards targets on the left side of their visual field in the order of 500ms [4]. Fitts' law is a well understood concept in the field of human computer interaction, often used to benchmark input devices and inform design decisions, e.g. about user interface layouts. In this paper we want to understand whether a model based on it can diagnose and quantify neglect.

III. Design and Modeling

The general concept of the game was inspired by the arcade game 'whack-a-mole' that has targets (moles) randomly appear from holes for a short time that the player needs to hit (whack) with a soft mallet before they disappear.

We implemented and evaluated a touchscreen based (iPad) game, in which targets appear and the player hits by tapping on them (see Fig. 1). To direct the player's gaze to the center after hit the target flies back to the center in a springing motion and a center button tap is required to spawn new targets. The targets remain on the screen for three seconds before disappearing, requiring the player to hit the center button again. The collaborating therapists advised to keep game play within 10 minutes and a game takes ca. 8 minutes to complete. The game was iteratively designed with

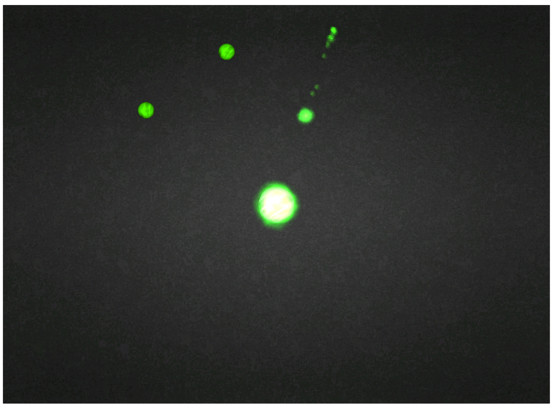

Fig. 1. Center button and multi-targets after a hit

patients involved as testers. These tests informed design choices such as target expiry times, their placement, activation size, and audio-visual stimuli during gameplay, both for spawning and feedback when hitting them.

The purpose of the game is twofold: a) to test whether we can infer the patients' condition and degree of neglect from game play data and research which performance indicators would be fit for this purpose. b) To provide opportunities to expand the visual field of the patients by presenting stimuli at the edges. Initially the targets appear close to the center and successful hits increase the radius in discrete steps of 10% from the current maximum distance hit. Expired targets reduce the radius such that patients should be typically playing close to the border of the visual field while not finding the task too challenging.

The central parameters in modeling patients' performance are the distance at which targets expire and the time between a target randomly appearing at various distances and the player hitting the target, which we will refer to as hit delay. Everything considered equal, longer hit delays and expired targets indicate time spent searching for targets (on the neglected side). The game used circular targets with a 6mm visual diameter and 12mm activation diameter. The distance of the targets from the center button ranged from 1.2 to 10cm. When modeling user performance according to Card *et al.*'s model human processor (MHP) [5] in our game design the hit delay includes the following times:

a. to perceive that a target has appeared (perceptual processor: 50-200ms cycle time),
b. for the cognitive processor to decide to act on it (25-170ms),
c. the movement time from the center to the target

Fitts' law [6] has been used to model movement time (*MT*) depending on the size of the target and its distance from the origin of the pointing device:

$$MT = a + b\ log_2(2D/W) \quad (1)$$

The parameters D (distance to the target) and width (W) are known while a, a reaction time component, and b can be determined through modeling. In our case a would comprise the above parts a. and b. Fitts' law can be applied to two dimensional targets when using the smaller of the target dimensions – height and width (W) – as the input for W [7]. Our circular targets yield a constant width (W), regardless of approach angle. We averaged the cycle times of healthy older adults (60+) reported in Jastrzembski & Charness' survey [8] for each category – perceptual (178ms), cognitive (115ms) and motor processor (139ms). Combining this with Card *et al.*'s MHP in [5] we obtain an information transfer rate of 112ms/bit for elderly compared to 78ms/bit for young adults. Together a. and b. above should take older adults (293ms) around 120ms longer than younger adults (170ms).

IV. Trial

Two left-side neglect patients (female aged 62 and male, 77) and, as a comparison, two patients with attention deficit disorder (69, 78) participated in a nine day study during which the neglect patients played 14 times on average (20, 8) and the attention deficit patients nine times each on a 10.1 inch Asus transformer TF300t tablet with 132ppi resolution. At the beginning and the end of the study the participants played one video recorded session for further analysis. We contrast the patients' data with performance from six students (mean age 22) and four elderly adults (mean age 76) who each played one session. All participants were right handed.

To better understand how patients interacted with the game we cross-compared the video footage from the patients' first and last sessions with the data logs from the game. Many logged touch events were misclassified as misses (touching the screen without hitting a target). These false negatives were due to the targets being too small to hit, or the participants double tapping or unintentionally touching the screen with a part of their hand apart from their main input fingertip. The average offset from the target center on a miss was 7.65mm with a standard deviation of 1.95mm. The bulk of misses (77%) occurred within 6 to 9mm from the target center.

V. Results

The trial lasted for nine days and we report statistical tests based on a split into the first and second half (4 days) of the trial. A game session typically lasts eight minutes unless the player manages to expand the target radius to the maximum, which did not happen during the trial.

Fig. 2 summarizes all hit delay performance by target distance averaged by patient group. As expected the neglect patients had problems with targets on the left. Comparing their left and right hit delays shows that once targets are further away than 8cm from the center the delay on the left increases much more than on the right. Their performance on the right hand side is similar to the elderly and students in shape but with a constant offset indicating that this was due to reaction time differences when the target appeared or when tapping on it. The students performed best and the main difference to the elderly was an approximate constant offset of on average 170ms, which was in line with the MHP. The patients had very different approaches to hitting targets: two would use only the index finger on the dominant hand with

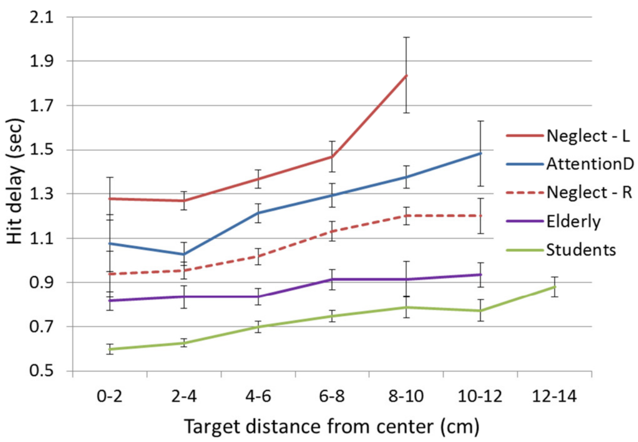

Fig. 2. Participants' averaged hit delays by distance with .95 confidence interval error bars

the hand held above the tablet, while another would shift between hands. One would rest his hand at the lower right hand corner of the tablet while using multiple fingers and minimal hand movement.

The game regulates the distance between the center and the targets based on player performance. Both in the first and second half of the trial the neglect patients achieved significantly lower distances on average on the left (9.97 cm) compared to the right (10.44 cm) side according to t-tests (p<.01, p<.05), while there was, as expected, no significant difference between left and right for the attention deficit patients. Neglect patients right hand side game performance did not improve as measured by average target distances. Our subsequent analysis focuses on their performance on the left. During the second half of the trial the neglect patients on average managed to hit targets further away on the left compared to the first half but this difference was not significant. However, during this period the patient who used the game most often (2.2 times per day) managed to hit targets significantly further away on the left hand side (9.4 - 8.8cm, p<.05).

See Table 1 for the averages of the model parameters, which are based on hit delays by each participant from roughly 40 single targets. Despite the game mechanic lending itself seemingly well to modeling the data with Fitts' law the R square fit was generally low for all participants but the students. This was not particular to the first game sessions only. We checked all played sessions by all participants and found the R^2 for a Fitts' law fit to be on average .14 with a standard deviation of .11 and there was no increase over time. However, taking averages of the left and right *a* values from Table 1 for elderly (0.55) and students (0.43) results in a difference that can accommodate the reaction difference the MHP would suggest. The patients had larger values. Both the students and the elderly informational transfer in bits/sec (the inverse of *b*) in Table 1 are close to Fitts' results, which were between 8.9 and 12.6 bits/sec [6]. In our video observations the patients did not try to hit targets as quickly as the elderly and students did, but appeared more relaxed.

We further investigated how touch input offsets from the target center evolved over time (see Fig. 3). All participants hit targets with a right offset from the center, but this was least pronounced for the students (0.3 mm). Over time the patients improved their target hit offset. Both patient groups improved their horizontal offset with the attention deficit patients having similar offsets to the students during the second trial half. The neglect patients only had a small change to the left over time. The students were the only participants to hit above the center line of the targets, while both attention deficit (-1.95mm) and neglect patients' (-1.65) hits started with offsets far below the line but over time moved upwards. In the absence of existing models we ran a forward stepwise multiple logistic regression based on a minimum of the Bayesian information criterion (BIC) on all game play data per session. The aim was to predict whether the player had neglect or not from all model parameters as shown in Table 1 along with game session performance indicators (averages of x-axis distance of expired targets from center (*e*) in cm, x- and y- offsets in mm from target center (*x*,*y*), average hit delays (*h*), average target x-axis distance from center (*d*) in cm) as predictors. For this limited data set (a total of 52 sessions) a binary logistic regression model had a fit of R^2=0.91 with the following significant predictors and their parameter coefficients:

$$z = -2.25 + 0.8a_L + 1.98b_L + 0.04e_R + 0.11x_L + 0.15d_R + 0.74h_L - 0.96h_R \quad (2)$$

This equation can be used both for the binary classification and as a measure of rehabilitative progress. The therapist deemed the game fit for purpose as it was easy enough for all patients to engage with, which is, according to her, a common problem with other games and some diagnostic tests, which frustrates patients. The patients and our elderly participants found the summary screen at the end of the game important and insightful. It detailed hits/misses by angle and distance from the center and the overall reaction time for each angle as neglect patients are often not aware of their impairment. The therapist was not able to judge these differences in reaction times from observation. The patient who played most frequently and had been aware of her progress inquired about a copy for future home use claiming it was helping her rehabilitation.

TABLE 1: AVERAGED FITTS' LAW MODEL RESULTS OF FIRST GAME

	L/ R	avg. *a*	avg. ci *a*	avg. *b*	avg. ci *b*	avg. R^2
Neglect	L	0.70	-0.21 1.60	0.25	-0.06 0.56	0.09
	R	0.59	-0.47 1.65	0.19	-0.12 0.50	0.17
attentionD	L	0.62	-0.11 1.35	0.22	0.01 0.42	0.15
	R	0.83	0.18 1.48	0.13	-0.07 0.33	0.10
elderly	L	0.72	0.56 0.89	0.05	-0.01 0.11	0.08
	R	0.37	0.04 0.70	0.20	0.08 0.31	0.24
students	L	0.46	0.31 0.62	0.11	0.05 0.16	0.28
	R	0.39	0.20 0.58	0.12	0.05 0.19	0.24

VI. DISCUSSION

We attribute the high accuracy of classification to our small sample size and leave the validation to larger scale studies. During the duration of the trial the performance profile of neglect patients was evident and we found trends and significant progress in hitting further away targets on the left. We can rule out that getting accustomed to the game improved the neglect patients' performance as this would yield gains on the right side and in the attention deficit

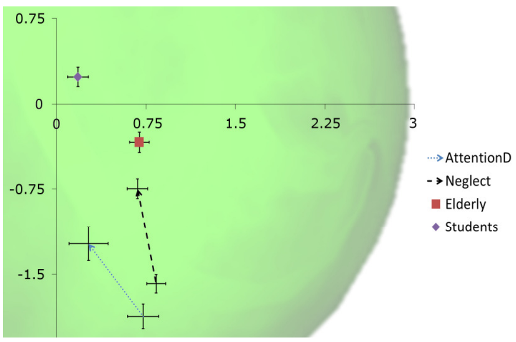

Fig. 3. Averaged target tap offsets (in mm from the target center) with .95 confidence interval error bars during the first and second (end of arrow) half of the trial

group's performance, too. However, a coping strategy, e.g. shifting the gaze from the center button away further to the left when pushing it, could explain the improvements. This could be controlled for in future studies using eye-tracking. Instead we checked the patients' rehabilitation progress from the clinic's cognitive entry and exit scores of the functional independence measure (FIM), which showed that these two made substantial progress during their stay. So the in-game gains are supported by a game-independent measure. However, both are outliers in terms of cognitive improvement compared to patients with similar cognitive entry scores and rehabilitation, and future studies need to show whether the current design and its discrete steps are sensitive to detect small rehabilitative progress.

To be useful as a diagnostic tool we hoped to use data from a single session to diagnose and track progress. To this end we modeled the patients' performance in each session with Fitts' law and subsequently used a stepwise binary logistic regression to predict neglect from the obtained data. For better comparison with the elderly and students we took only the first game session data for each participant and fit the hit delays of targets not occluded by the right hand when tapping the center button with the target distances to Fitts' model. We modeled targets on the left and right hand sides separately. The time difference between hitting equidistant left and right targets (500ms offset between the neglect-R and neglect-L curves in Fig. 2 for targets up to 7cm away) are in the same range as the motor neglect reported in [4]. While we cannot be sure as we did not control for motor neglect in the patients, it would be an interesting application of the game since typical test batteries as the behavioral inattention test (BIT) do not cover motor neglect.

The poor fit of the Fitts' law model showed that other factors play a role in the variation of hit delays, but that does not mean that the model is not applicable in this case. First, the results of the elderly and students in terms of information transfer (inverse of b) match well. Some of the poor fit is most likely due to not playing as fast and consistently as possible and over a much longer continuous period than Fitts' experiments lasted. While the game design aimed at centering the player's eye fixation before each target appeared we cannot guarantee adherence. This may introduce result variance for the neglect patients. Further variation might stem from game design decisions. There was only one cue to encourage the player to play fast – an increase in pitch of sound played when a target was hit. But the expiry duration was set relatively high so that the patients would not be frustrated by their indications. While multi-targets create potential confusion due to a change of rhythm from the established and monotonic center-then-target-tapping cycle, they made the game more fun, an important consideration for self-rehabilitation. As one of the elderly players spontaneously remarked: "*Oh, hitting these three is fun.*" The symmetric design led to targets appearing underneath the hand when pressing the center button. This might lead to people moving their hand outward affecting the travel time for left and right hand targets differently.

Students were the only participants who hit the targets slightly above the center, which could be due to their high amount of touch screen experience. Over time both patient groups adjusted their acquisition of targets upwards. This could be because they gained touch screen experience, particularly for these small targets or due to rehabilitation progress. However, we did not obtain the patients' prior touch screen experience and can therefore not analyze the data in relation to this.

Further limitations stem from running a field study. For example, we could not control for viewing distance at which the device was held, which would very likely influence results and add result variation. We could not guarantee that the patients were the actual users of the game for each session. However, the game performance of the sessions attributed to the neglect patients consistently showed the profile of a neglect patient.

VII. Conclusion

We designed a whack-a-mole inspired tablet game that was simple enough to be played by neglect patients to compare their target hit delays and distances to those of patients from attention deficit disorders as well as students and elderly. We found evidence that a model based on Fitts' law analysis of and in combination with in-game data can be used to identify and quantify neglect. Future work should evaluate whether the obtained model generalizes to a larger neglect patient population both for identification and to track their rehabilitative progress.

VIII. Acknowledgments

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