Developing Adaptive Mental Health Games using Player-Patient Modeling

Abstract
Noncompliance with treatment is particularly pronounced in mental health care, where interventions must be applied to a group of individuals who not only differ widely in their health status but also in their response to treatment. In the field of game-based cognitive training, dynamic difficulty adjustment (DDA) is increasingly explored as a means to boost treatment effects by making treatments individualized and engaging. However, DDA assumes playtesting with a sufficiently large group of end-users. This is challenging for certain mental health populations. Here we present the use of player-patient models and simulations to optimize DDA algorithms for a patient population suffering from hemispatial neglect after stroke. We demonstrate how player-patient models allow to pretest algorithms when it is not feasible to test a sufficiently large number of patients.

Author Keywords
Hemispatial neglect, adaptive play, player modeling

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Introduction
When dealing with mental health disorders, clinicians are confronted with the difficulty of keeping patients engaged in their treatment [7,10,13,22]. Patients may disengage from treatment or not seek help in the first place. This lack of compliance strongly reduces the effectiveness of both pharmaceutical and behavioral interventions. As such, increasing patients’ treatment engagement is of high importance in the field of mental health.

Games to Improve Treatment Engagement
In recent years, interest has grown to apply game mechanics to mental health interventions to increase treatment engagement [7]. Such interventions are based on the observation that games are often highly motivating and even addictive [11,32]. Many studies have indeed focused on the question: "Which elements make games fun or motivating?" [11,26]. This line of research has resulted in insights about the appeal of games which have been applied to many different therapeutic interventions [1,2,3,9,16,21,27]. Many studies have suggested that game mechanics can increase therapy engagement and several therapeutic games have been developed based on these suggestions. Nevertheless, little is known about the effect of gaming mechanics on treatment engagement itself [15,34].

From Games to Adaptive Games
Treatment engagement is not the only challenge when developing an effective therapy for mental health disorders. Patients often differ strongly in their needs with regard to treatment. For instance, in the field of cognitive and motor skill training, large inter-individual differences in the intact abilities and the learning capacity have been reported [10,12,17]. Dynamic difficulty adjustment (DDA) has been suggested as a way to develop such individualized game-based interventions [24,29,30]. Adaptive games are thought to increase treatment effects, because they target the abilities that are just beyond the reach of what the player can do without support ("the zone of proximal development"). Furthermore, adaptive games could increase motivation, because the player is not confronted with inappropriate levels of challenge. However, it is yet to be investigated whether treatment effects and treatment engagement are better for adaptive compared to non-adaptive games [29].

Developing Adaptive Games for Clinical Populations
When developing a game, game algorithms are often optimized and tweaked through multiple rounds of play testing with the end-user group [5,33]. However, this approach can be challenging when developing games for mental health. Repeated data collection within a sufficiently large sample of patients, representative of the clinical population, is indeed extremely time-consuming and may even be impossible when dealing with rare diseases.

Player Models for Adaptive Games
Here we suggest that simulations of game play behavior can overcome this challenge, revealing potential problematic aspects of the algorithms and therefore reducing the need to do player testing. Simulations have already been used to test the effectiveness of an adaptive algorithm for a game to train attention and executive functions in patients with traumatic brain injury [27]. In particular, these authors studied how well an adaptive algorithm modelled gamer ability and how well it could distinguish between
gamers with different learning rates [27]. Here we suggest to add characteristics of the player’s mental health disorder to the player model, that is, to go beyond modeling the player and towards a player-patient model. Simulations according to a player-patient model can be used to test how the game adapts to different types of patients. To do these simulations, a model (grounded in theory) of the player-patient must be developed that can predict the game play behavior. Based on this model, responses of the player can be simulated and used as input for the game and DDA. In the following paragraphs, we detail how we used a player-patient model and simulations to make informed choices on DDA in our line of research.

A Player-Patient Model of Hemispatial Neglect

Hemispatial Neglect
Our research group developed a new rehabilitation tool for patients suffering from hemispatial neglect after unilateral stroke. These patients fail to attend one side of space [18], which restricts daily life functioning and limits recovery of other motor and cognitive functions affected by stroke [8].

Rehabilitation of Hemispatial Neglect
Although many endeavors have been made to treat hemispatial neglect, most of them failed to generate long-lasting treatment effects that transfer into daily life [6,14,19,21,23]. Additionally, due to a lack of disease insight, it can be difficult to motivate neglect patients to engage in their treatment. A virtual reality (VR) serious game could tackle both obstacles of transfer and engagement, by training patients in a more realistic environment in 3D space and by motivating engagement through gaming mechanics [1,4,7,16,20,25,30,33]. Furthermore, adaptive mechanics can be used to make an individualized treatment that can account for the large inter-individual differences in the severity of hemi-spatial neglect.

Designing an Adaptive Rehabilitation Game
Our newly developed VR game aims to retrain attentional orienting in patients with hemispatial neglect. In this game, patients must discriminate between two different types of target stimuli. The target stimuli can be presented at different locations in the realistic VR environment. We developed an adaptive game in which the difficulty of the game is adjusted based on the performance of the player-patient. The goals of the algorithm are: 1) to present stimuli more often on the neglected than the non-neglected side of space, irrespective of performance ("Forced Adjustment" [28]), and 2) to support the player to detect stimuli in the neglected field successfully by dynamically changing the duration of stimulus events based on the performance level ("Scaffolding"), and 3) to adjust the difficulty of the game at a level that fits the preference of the player ("Player Controlled Adjustment Policy"). To develop and optimize our DDA algorithm, we used simulations based on a player-patient model. The aim of these simulations was to reveal whether the response of the forced adjustment algorithm to the characteristics of the player-patient fitted our treatment goals.

Forced Adjustment
The forced adjustment algorithm aims to present stimuli more often in the neglected than in the non-neglected side of space, irrespective of performance. To accomplish this, a truncated Gaussian distribution determines the location of the target events in the
game (Figure 1). The mean of this distribution represents the location where targets will most likely appear. The mean is initialized at the center of the visual field (assuming the observer looks straight ahead) and is adjusted based on the median locations of the missed and incorrectly discriminated target events at a fixed rate throughout the game.

**Patient-Player Model**

We simulated data based on a model representing the visuospatial asymmetry, characteristic of hemi-spatial neglect [8,18]. In this model, the probability of a correct response to a stimulus (detection probability) depends on its spatial location, according to a cumulative Gaussian distribution with the parameter \( \mu \) (location where 50% of targets are detected) and \( \sigma \) (the slope of the cumulative Gaussian distribution) (Figure 2). The cumulative Gaussian distribution is restricted to one side of space by a parameter that acts as the boundary between the neglected and the non-neglected field (\( \gamma \)). The last two parameters in the model, \( \lambda \) and \( \epsilon \), reflect the percentage of failures to detect the target independent of its location and the minimum level of performance of the player. This patient model was updated throughout simulated trials to represent the effect of learning and the effect of an increase in difficulty throughout the levels of the game, making it into a player-patient model. The learning rate of the player was modeled by shifting \( \gamma \) to the left side as a function of the number of trials that the player has already completed. A smaller \( \gamma \) represents a smaller neglected field. The effect of higher levels was modeled by reducing the probability to detect targets located in the neglected field as a function of the difficulty of that level (Figure 3).

**Simulations**

Based on our player-patient model, we were able to predict the probability of a correct response given the spatial location of the stimulus, the difficulty of a level and the number of previously completed trials. For each trial, this probability was transformed into a hit or miss according to a Bernoulli distribution and the resulting pairs of coordinates and hits or misses of each trial were used as input for the forced adjustment algorithm. The mean of the truncated Gaussian distribution that determines future target locations was shifted to the location where previous targets were missed. Then, the probability of a correct response for these new locations was estimated and new trials were simulated. This procedure can be repeated for different combinations of player-patient and game features to reveal how the game adapts to different types of player-patients. Our simulations showed that the forced adjustment algorithm succeeded at presenting targets on the neglected side of space independent of the player’s performance. Furthermore, the target locations moved more towards the peripheral (neglected) side of space for patients with a stronger spatial bias.

**Conclusion**

In this paper we have demonstrated the approach of using a player-patient model to optimize DDA algorithms in the context of a game-based intervention to treat hemi-spatial neglect. Our approach may inspire other developers of mental health games to pre-test algorithms using player-patient models. Such models force developers to make each assumption underlying the game design explicit. In general, they can stimulate scientific progress to understand and treat mental health disorders better by requiring of accurate models.
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References


