Diving into a Decade of Games for Health Research: a Systematic Review

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Abstract. Recent years have been characterised by a rising interest in using entertainment computing to monitor, maintain, and improve human health. This is observed in the many systems and applications that leverage the benefits of a playful and enjoyable experience to provide a technology-enabled health intervention. This paper reviews one decade of papers (679) published at the intersection of health, entertainment, and technology to determine trends, studies' characteristics, type of solutions, domains of application, and study purposes. Results show that there is a growing body of research in the area, with the majority of studies providing solutions for rehabilitation and addressing motor conditions related to stroke and/or fitness. Where half of the solutions reported are custom made, the bulk of those studies is performed with the purpose of evaluating the solutions proposed or validating their efficacy. In 80% of the cases, the studies are performed with subjects from the target population with sample sizes that have been steadily increasing over the years.

Keywords: Health, Entertainment, Technology, Computing, Review, Games, Simulation, VR, AR.

1 Introduction

Consumer technologies for gaming and entertainment have become so precise, affordable, and pervasive that their application has gone well beyond pure entertainment. With a variety of application domains, from education to business, entertainment computing is increasingly used in the health domain. This gain in popularity has been explained, for e.g., with the proliferation of low-cost technologies, the realisation of the potential of entertainment and playful elements in extending motivation, and the widespread access to technology in general (Cipresso et al. 2018; McCallum 2012; Nacke and Deterding 2017; Wattanasoontorn et al. 2013).

In health, entertainment computing has been used to support the monitoring, detection, treatment, rehabilitation, and education of patients and non-patients alike (Wattanasoontorn et al. 2013). These technology-enabled solutions have taken the

form of simulations, serious games, or gamified applications that leverage the potential of virtual/augmented/mixed reality and/or game elements to support a variety of health domains and conditions. Because the applied research areas at the intersection of health entertainment computing have become so wide, it is important to investigate the research that has been conducted in this area to understand how the field of health entertainment computing has evolved over the years and what specific contributions have been made by that field of research. To our best knowledge, no such analysis has yet been done. This paper engages in a systematic review of the literature of the research published between 2004-2014 at the intersection of health, entertainment, and technology to develop an understanding of the main contributions and areas of application in the field. Specifically, we investigate the i) characteristics of the studies, from purpose to participants involved, etc., ii) types of solutions that have been produced, and iii) purposes of the interventions and their main domain areas. A main research question guided the research: How has the field of health entertainment computing evolved over the years? that we broke down into: i) Which are the most common domains of intervention?, ii) What type of solutions are being produced?, and iii) What are the characteristics of the studies that are being conducted with those solutions?

After presenting our search and data extraction strategy, we present our results and findings, which are based on the full text analysis of 679 articles. We conclude with a discussion and the identification of future avenues of research. This research brings a shed of light into our knowledge and understanding of the multidisciplinary and vast field of health entertainment computing, highlighting strengths and limitations as well as general trends and characteristics.

2 Research Approach

The search strategy for this review was as follows: ((health OR rehab*) AND (((serious OR computer OR interactive OR video OR online) AND gam*) OR exergames OR gamification OR ("virtual reality" OR "augmented reality" OR "mixed reality"))). To maximize coverage, the authors conducted a systematic search in three databases: IEEE Xplore, PubMed and the ACM Digital Library. Articles included were: dated between January 2004 and December 2014; peer-reviewed; in English; involving five or more subjects; application domain related to health; and use of entertainment technology. Articles were excluded when: not accessible/possible to locate; in form of book, poster, demo, workshop, keynote, study protocol, review, editorial, letter, commentary, clinical perspective or appraisal.

The above-described searches yielded a total of 6767 articles. Two reviewers screened all titles, abstracts, and type of publication for eligibility, according to the inclusion and exclusion criteria. When necessary, the reviewers downloaded the article and skimmed it to determine article eligibility. Articles that were deemed irrelevant were discarded (5147). From the remaining 1485, 124 were not possible to locate/download and 108 were dated outside the date range defined (2004-2014). The full texts of the 1253 articles that remained were downloaded for full text eligibility assessment. Figure 1 shows an overview of the process.

Three pre-coding training sessions were carried out involving all reviewers coding five articles to refine goals, themes, concepts and a preliminary data extraction form. Subsequently, a final version of the data extraction form was created that included the following fields: Year of publication, Type of publication, Venue, Reason for exclusion, Study participants' age / same as target / sex / health condition, Health and application domain, Stage of the disease, Type of intervention, Type of technology, Purpose of technology, Sample size, and Purpose of the study. Later, reviewers independently coded four articles and an agreement percentage of 93% among reviewers computed; which was deemed appropriate for subsequent independent coding. Three reviewers divided the remaining articles and examined them independently. Questions and conflicts were resolved by discussion and consensus in regular reviewers' meetings. As a result of this, 574 articles were excluded, and 679 articles were deemed relevant for the research presented in this paper (Fig. 1).

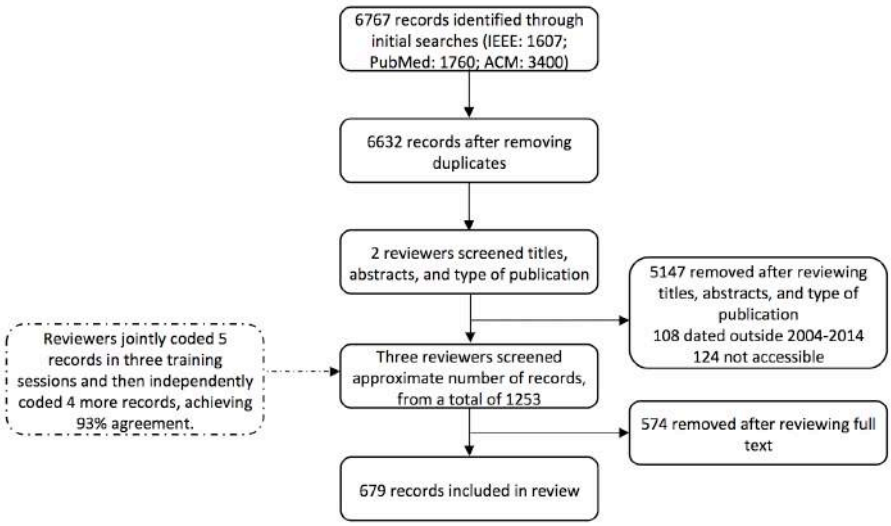

Fig. 1. Overview of screening and selection process.

3 Results and Findings

Figure 2 shows the yearly trends for the included articles. A 10-fold increase of publications can be observed between 2004-2014, consisting mainly of conference contributions until 2012, and later matched by journal publications.

Table 1 shows the top five conference and journal publication venues in this area. Whereas there seems to be a large consensus on the most relevant conference venues in the area (top five totalling 171 publications), this is not the case for journal venues (top five totalling 73 publications). Interestingly, a larger number of conference publications is observed on odd years (Fig. 2). This may be due to two of the most contributing conferences taking place every two years, the International Conference on Virtual Rehabilitation and the IEEE International Conference on Rehabilitation Robotics.

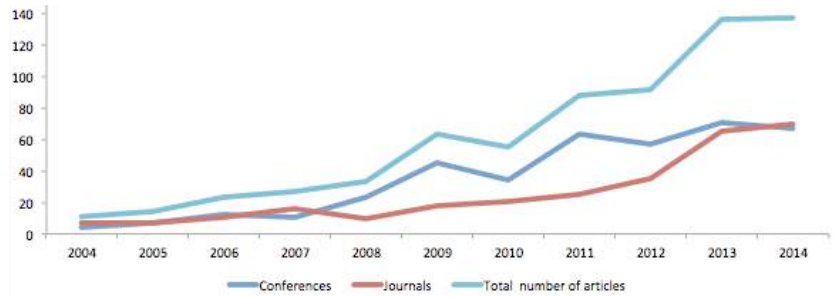

Fig. 2. Yearly publication trends.

Table 1. Publication venues top five.

Conferences - Top Five	Journals - Top Five
− ACM SIGCHI Conference on Human Factors in Computing Systems (60) − International Conference on Virtual Rehabilitation (51) − IEEE Annual International Conference on Engineering in Medicine and Biology Society (31) − IEEE International Conference on Rehabilitation Robotics (17) − ACM SIGCHI Conference on Interaction Design and Children (12)	− Journal of NeuroEngineering and Rehabilitation (18) − IEEE Transactions on Neural Systems and Rehabilitation Engineering (17) − Studies in Health Technology and Informatics (15) − Disability and Rehabilitation: Assistive Technology (12) − Annual Review of Cybertherapy and Telemedicine (11)

The analysis of the studies included in this review presented work at different stages of development and with different purposes. We defined the following categories: Conceptualization, User Research (before development), Prototyping, Evaluation (of the system itself), and Validation (of the outcome of the system). Many contributions presented multiple studies or contributions in different stages. Fig. 3 shows that most studies contain a Validation study (368) aiming at verifying if the proposed system fulfils its health-related goal. Nonetheless, articles devoted to technical aspects such as Evaluation (293) of the functioning of the system and Prototyping (74) are also frequent. There are, however, fewer contributions concerning the Conceptualization and User Research phases, which are crucial steps in the development of health entertainment technologies.

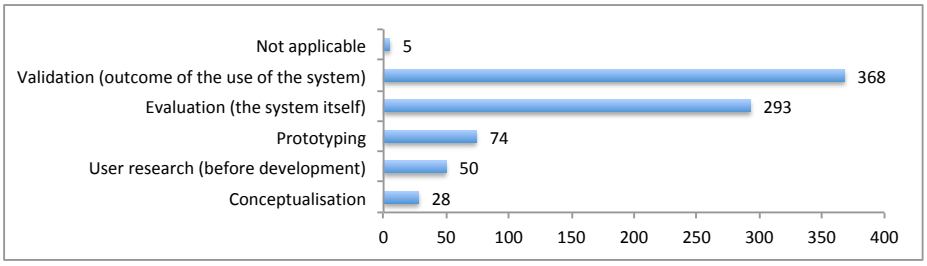

Fig. 3. Purpose of the study.

The largest sample size identified was 1943 participants, being the most frequent 10, the average 41 and the median 19. Except for a few rare cases, journal publications tend to present slightly larger sample sizes (Mode: 20, Mean: 45, Median: 23) than conferences (Mode:10, Mean: 37, Median 16). As for the evolution over time, the sample size has increased during the 2004-2014 decade for both conference and journal publications (Fig. 4), what is consistent with an increase of clinical and field trials and less proof-of-concept studies.

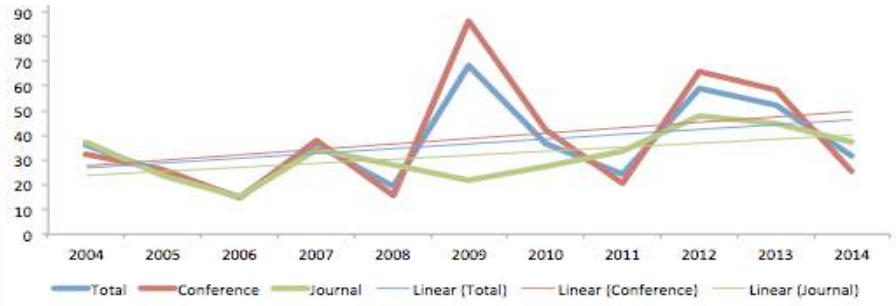

Fig. 4. Average sample size across time and corresponding linear regressions.

Although sample sizes have increased over time, the information provided on the samples is often insufficient. Most studies do include male and female participants (455), and only a few solely male (24) or female (18) participants. However, a large number of studies (181) do not provide information on the sex of participants. Similarly, of the included articles, 120 do not report on the age of their participants. The most frequent participants are, in this order, adults (18-49 years old), young senior (50-64 years old) and senior (65-84 years old). Some studies include participants of multiple age groups, and hence have been accounted for in the different age ranges. With respect to the condition of participants, 285 studies included patients, 211 included healthy participants, 94 included both, and 73 studies did not indicate the condition of their participants.

To analyse the stage of the disease of the study participants, we used Merril's taxonomy, as summarised by Wattanasoontorn et al. (2013), that considers the following stages: Susceptibility, Pre-symptomatic, Clinical disease, and Recovery, Disability. From the studies included in this review, 160 included participants in Susceptibility stage, 24 in Pre-symptomatic stage, 249 in Clinical disease stage (including transitory or acute conditions), 228 in Recovery stage (chronic conditions), and 18 in Disability stage, meaning the aim is not to recover from the disease but rather to increase quality of life. Studies considering multiple stages were accounted for in each of the stages. For 63 studies this information was not available and for 75 this taxonomy was not applicable.

Each article focused on a specific type of digital solution, which we grouped under one of the following categories: virtual reality, augmented reality, mixed reality, and other types of solutions (e.g. games, mobile games, desktop applications, etc.). We found that most studies used virtual reality (384) and few would refer to applications as augmented reality (29) and mixed reality (18). Instead, a large number of studies would refer to other types of technologies (249). It was not possible to determine the type of technology used in 29 of the reviewed articles.

We were also interested in finding out whether the solution in use was (was not) commercial. We found that 50% of the solutions were custom made, while 26% were commercial, and for 24% of the articles it was not possible to determine the nature of the solution. While the fact that half of the papers report on custom made solutions is not surprising, especially because this study is sourced on research papers, this also reflects the potential that researchers perceive in embedding entertainment in technological solutions targeting health and also a limited number of commercial alternatives. Hence, this important investment by researchers may foresee an increase of solutions in the market leveraging play, game elements, or some sort of entertainment to attain health goals.

To determine the purpose of the technologies in the reviewed papers we used Wattanasoontorn et al. (2013) classification, who created a taxonomy of serious games by target group: patient / non-patient. Targeting patients, Wattanasoontorn et al. (2013) considered: health monitoring, detection, treatment or therapy, rehabilitation, and education, for non-patients: health and wellness games, training and simulation games for professional, and training and simulation games for non-professional.

Overall, the results show that studies aiming at patients (664) seem to be more expressive than those targeting non-patients (172). The great majority of articles targeting patients reports on studies which purpose is rehabilitation (315); these are followed by studies aiming at treatment or therapy (205). A smaller number of studies targets health monitoring (50), detection (55), and education (39). When looking into technology for non-patients, the health and wellness category gathers the largest number of studies (156), while training and simulation games for professional (4) and non-professional (12) numbers are residual (Fig. 5). For the correct interpretation of results, it is important to mention that studies sometimes report on more than one single purpose. This is the case of the combination of treatment or therapy plus rehabilitation (63) and of health monitoring and detection together (20). Still, these numbers are less expressive than the ones in categories such as rehabilitation, health and wellness and treatment of therapy alone, which are the three areas that have been receiving the most attention by the research community working in the intersection of health and entertainment technologies.

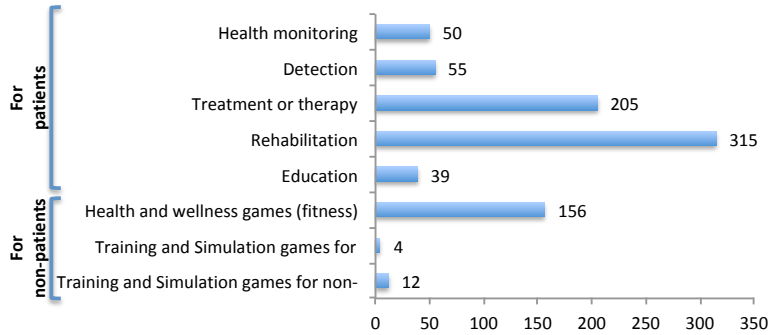

Fig. 5. Purpose of technology.

We also investigated whether interventions were tackling motor, cognitive, social, or other domains of intervention. Regarding this, results show that the vast majority of

studies focused on motor (454) concerns, followed by studies addressing cognitive (132) issues. A smaller number of studies dealt with social (47) or other types of issues (81). In this category we would include, for example, studies dealing with pain, or general health awareness. So far, there has been a tendency on focusing on one single domain of intervention, still it is important to note that some studies address more than one domain. This is the case for studies focusing on motor and cognitive (16) or on motor and social (14) domains. While still not expressive, there seems to be a tendency towards holistic approaches in more recent years, where we found the above combinations as well as others combining all three domains (2). It is noteworthy that from a total of 40 studies, 35 are dated 2009 or later.

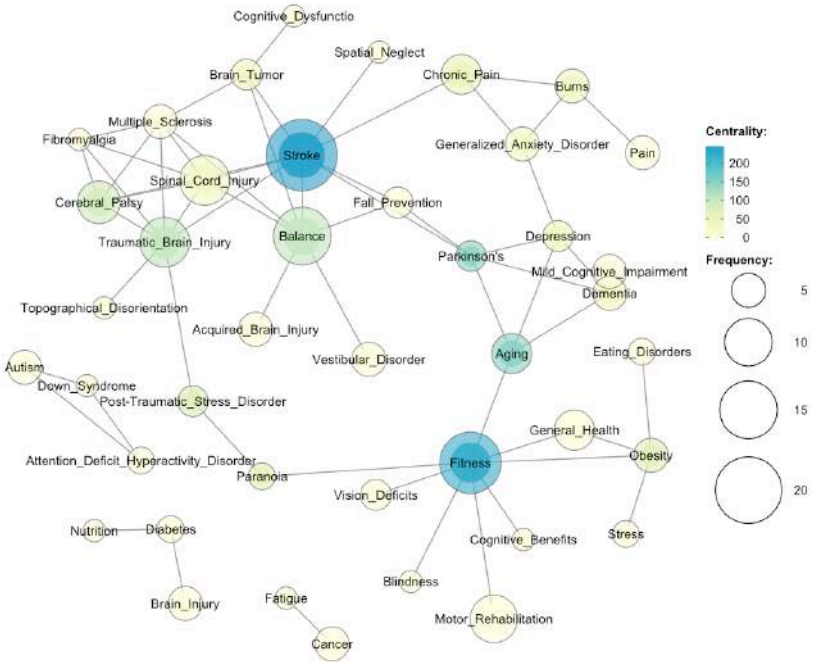

Fig. 6. Co-occurrence network diagram of domain of intervention.

Each study targeted one or more intervention domains (e.g. balance, stroke, cognitive rehabilitation), and those were labelled as reported by the authors. This produced a heterogeneous number of labels for each article indicating one or more intervention domains. We computed the co-occurrence of domains by first uniformizing the nomenclature for multiple terms referring to the same domain (such as TBI and traumatic brain injury), and second producing a co-occurrence network diagram (Higuchi 2016). The resulting network diagram shows us the most frequent intervention domains as nodes, its size according to the number of occurrences, and colour indicating how central the role each domain plays in the network (betweenness centrality). Nodes (domains) are connected through edges according to their simultaneous frequency of appearance. For this analysis, we only considered cases of 3 or more co-occurrence of domains. This analysis shows that the most central

domains were Stroke and Fitness followed by Aging and Parkinson's. However, the most frequent co-occurrence of terms was Stroke, Fitness followed by Balance, Traumatic Brain Injury and Spinal Cord Injury. The network shows the relations between terms and how they cluster (Fig. 6).

4 Concluding Remarks

This paper reviewed health entertainment computing research published between 2004 and 2014. Results show that this area of research has been growing over the years with a sustained increase in conference and journal publications. The largest subset of contributions (~58%) still focuses on the development, prototyping, and technical evaluation, with only 54% of the reviewed publications evaluating the outcome of use of the proposed tools. This may mean that the impact of some tools is rarely assessed. On a positive note, the sample sizes have grown through the years. More importantly, 80% of the samples included their target population. We did not identify a preference towards a specific type of technology, but data show most solutions were designed for motor interventions, and for rehabilitation purposes. Finally, the most common intervention domains were Stroke and Fitness.

This study has some limitations that should be considered while interpreting the results. First, the search criteria and chosen keywords used for identification of the papers may have excluded relevant work. Furthermore, because of the long-time span needed to review the 679 papers, the assessment criteria of the reviewers may have changed over time. To this extends that, unless explicitly stated, information was tagged as 'not available', and that, as in any review process, the information available was subject to interpretation. Finally, this research is time-bound to 2004-2014.

The authors are currently reviewing the literature up to 2018. Our goal is to expand the results of this study to develop an overall understanding of the field of health entertainment computing and identify strengths, weaknesses, and future trends.

Acknowledgements

Research supported by BRaNT (PTDC/CCICOM/30990/2017) and MACBIOIDI (INTERREG program MAC/1.1.b/098).

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