THE IMPACT OF AUGMENTED REALITY TECHNOLOGY ON PHYSICAL REHABILITATION

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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AUGMENTED REALITY USAGE IN PHYSICAL REHABILITATION

Augmented reality (AR) is a relatively recent technology that has been developing in various fields. Augmented reality is the human-machine interaction which projects an overlay of virtual images and components onto the physical world. It has begun to be incorporated into physical rehabilitative services in recent years as a new means of improving rehabilitation for patients (Viglialoro et al., 2019, p. 1). An enhanced overlay of visuals can provide people with useful information in an inconspicuous way that does not heavily intervene with their surrounding environment. The purpose of this STS research paper is to analyze the current state of AR within physical rehabilitative services and project potential scenarios for future widespread implementation. This research aims to shed light on assimilating new technology into aspects of healthcare, which should result in improved recovery and lowered costs for consumers. The topic was chosen from interests in technology that change the way people view and react to their immediate environment, along with personal experience in work related to accessibility for other people.

The technical topic involves collaboration with The Sum, a Charlottesville, Virginia non-profit organization which promotes personal growth and diversity. The Sum offers a Power of Difference Assessment (PDA) to help individuals explore their demographic biases by providing different scenario statements for users to express their personal alignments (The Sum, n.d.). Upon completion, results are generated and categorized across demographics, areas of strength, and areas of growth to help reveal internal demographical biases. The goal of the capstone team is to improve the existing PDA for better usability, accessibility, and organizational management. Aspects of the technical involve consideration for users with physical disabilities, which loosely couples with the research of my STS topic. The two are coupled by the link in

people who are physically injured or disabled, which pertains to the demographics portion from the assessment within the technical topic while also relating to the people who undergo physical rehabilitation, which is the focus of the STS topic. In exploring the STS topic, the research question that this paper analyzes is: How does the implementation of augmented reality benefit patients' health and motivation when undergoing physical rehabilitation?

PARALLELS DRAWN BETWEEN EXISTING TECHNOLOGY

Rehabilitation of any type can generally be performed in one's own home or through a clinical office. Physical therapy also falls under the category of rehabilitation and is often performed based on a recommended program of exercises that is adjusted by doctors for patients suffering from some form of physical injury (Smith, 2017, para. 9). Negative characteristics commonly associated with physical rehabilitation include loathsome repetitiveness and pain, often leading patients to unwillingly follow their recommended program (James, 2013, para. 5). Incorporating new methods or tools into the traditional process can even add a form of gamification for people. Gamification aspects allows patients to focus on their prescribed routine while working towards a goal, enhancing their experience and keeping them motivated through game-like elements within a non-gaming environment (The Interaction Design Foundation, n.d., para. 1). Augmented reality can supply patients with the benefit of gamification by transforming their normal physical exercises into something more entertaining using immersive video environments. Sustaining engagement among patients has increased the number of those who stay committed to their recovery program (Kestenbaum, 2016, para. 6).

A lack of sufficient widespread testing and data prevents immediate implementation of technology from being used by the public. For example, due to insufficient information concerning the cost of necessary equipment, an estimate must be made from a parallel with a

similar technology in order to determine future trajectory. As AR remains relatively new in comparison to most other technologies, it must draw upon potential parallels to provide substantial evidence of its impact. One technology that is representative of AR's struggle to cement itself within a healthcare setting is the computer-assisted topography (CAT) scan. As the CAT scan introduced a method of generating data that produced detailed images of the body from X-rays, it has similarities with AR due to the nature of the technologies focusing on visual elements (Computed Topography, n.d.). Since both the cost of equipment and method of implementation is variable, one must focus on the cost benefit analysis of the development of CAT scans in order to speculate on the viability for AR technology with physical therapy. Existing wearable technologies with visual overlays can be used as references for cost speculation as seen in Figure 1:

THE BEST AR SMARTGLASSES

AR glasses	FOV	Country	Release year	Price*
Epson MOVERIO BT-300	23°	Japan	2016	$699
Everysight Raptor	-	Israel	2018	$649
Google Glass Enterprise Edition	-	US	2017	$1,800
Kopin SOLOS	10.68°	US	2016	$499
ODG R-7	30°	US	2017	$2,750
Toshiba dynaEdge AR100 Viewer	-	Japan	2018	$1,899
Vuzix Blade Smart Glasses	-	US	2018	$799
ThirdEye Gen X2	42°	US	2019	$1,950
Vuzix M300	20°	US	2016	$999

Figure 1: Aniwaa Chart Comparing AR Glasses: Market values for wearable devices that are recommended for consumers based on cost, with data to suggest complications of implementing wearables as a means for physical therapy (Cherdo, 2020).

The values listed within Figure 1 present complications concerning the cost of implementing wearables with AR functionality. While the price of CAT scans is proportionally larger in comparison, that did not prevent them from becoming widely implemented within hospitals. The different slice counts from a scan will be disregarded in assessing the machine as a higher slice count inadvertently results in a higher price (Lindsey, 2019, para. 11). The technical cost of the machines can range from $65,000 for used and refurbished ones while new machines can roughly cost around $2.5 million (Glover, 2014, para. 7). The hospitals that can afford to purchase any of these machines are able to alleviate the cost depending on the number of patients that require it. Cost for each individual patient at different facilities varies due to this, with facilities having more frequent use of the machines seeing patients paying less overall in comparison to facilities where the machines are not used as often, making it difficult for the cost to be spread out (American Health Imaging, 2017, para. 6). Through a similar method, the cost of using equipment implemented with AR can be reduced by following the practice of facilities that use CAT scan machines. By spreading out the cost of equipment among the number of patients who visit for physical therapy issues, an economically feasible method of implementation can be achieved. It allows patients to also compare different physical therapy facilities based on cost and decide for themselves the one that is the most beneficial since the cost of the equipment can be dispersed among many individuals rather than making the price for individual higher.

GAMIFICATION OF PHYSICAL REHABILITATION

The nature of physical rehabilitation often requires patients to practice their routines within their own homes without the guidance from professionals. Without medical personnel present, the AR equipment and associated software require simplicity in its setup and execution.

Since most of the rehabilitative equipment will be focused on visuals, the main piece of equipment is generally a projector or headset. Some methods can involve the simple use of a TV, as the new environment can be created within the screen while displaying the patient's interactions having a direct impact (Kestenbaum, 2016, para. 6). Similar to the AR functionality that was used to market Pokémon Go, a camera with updated software and hardware specifications is sometimes all that is needed in order to be used by the consumer, with little to no difficulty on the user's end.

As with video games, AR holds the ability to introduce new gamification elements into the traditional repetitive cycle recommended by doctors for physical rehabilitation. Through fun and diverse engagement, patients are more likely to stick to their recommended programs for the entire duration, increasing the success rate of physical rehabilitation (Self, 2018, para. 2). As the programs help a wide range of people across various age groups with different needs, keeping patients engaged in their prescribed routines is an important issue that faces the doctors and therapists who work with patients. Evidently, by helping to raise patients' home engagement, doctors can help them lower their overall costs as well. From a study conducted on patient engagement, increasing patient participation through decision making support led to lower medical costs of 5.3 percent in comparison to patients who received normal support from their doctors (James, 2013, para. 14). The decrease of clinical visits is largely attributed to the lowered costs, but the effects from improved engagement also affect it. Due to patients having a higher success rate of staying with their program, most pains that they would otherwise require therapy for were properly cared for and less likely to reoccur in the future. A study was performed by David Veroff, a healthcare policy researcher and analyst at Health Dialog, to assess the impact of patients receiving enhanced decision-making support. Patients who received support were seen

to have 12.5 percent fewer visitations to hospitals in general compared to the control group (James, 2013, para. 14). The conclusion drawn from the study is that the low cost of shared decision-making models can be generalized to enhance patient engagement in the broader population. By increasing engagement, improved health outcomes, lowered costs, and better patient care are all factors that benefit from it. With the added effects of gamification from AR in physical rehabilitation, the increase in patient engagement can similarly be stimulated and create health and financial gains for patients.

The increased effects of patient engagement not only benefit themselves, but they are a contributing factor for helping to promote the clinics and doctors that treat them. Additional engagement leads to a higher achievement of satisfaction once rehabilitative programs are completed. An article researched and published by David Self, the Chief Strategy Officer of Keet Health, a leading patient relationship management software company, explored the importance of patient satisfaction. With higher satisfaction, patients have a better chance of referring other individuals. On average, satisfied customers are more likely to share about their positive experience with nine other people (Self, 2018, para. 9). Additional clients are an important part for growing and maintaining business. Since there is a positive correlation between user satisfaction and the number of referrals, it benefits healthcare employees to maintain a higher level of patient engagement in order to keep satisfaction high.

Augmented reality offers a unique type of experience for people when used to help promote physical exercise. A widespread example can be taken from Pokémon Go. The application based its game mechanics on the assumption that the person playing the game would be able to see the Pokémon from the game in a real-life environment that incorporated the use of GPS and camera functionalities on one's phone (Rapp, 2018). The AR aspect helped motivate

people to play the game more, prompting them to go outside and walk, leading the overall general populace to experience a positive health outcome from the game. Since the idea of playing a game for health benefits was a large success among many age groups, there was high satisfaction and engagement, which places great importance on consumer experiences. As evidenced in an annual Customer Experience Impact (CEI) report from 2011 referenced by Chaundera Wolfe (2012) from BusinessWire, the relationship between products and customers stated that around 89 percent of adults would swap their product brand in favor of a competitor if the product they used before resulted in a poor customer experience (para. 4). Mirroring the situation with AR's gamification in physical rehabilitation, the clinics that provide AR equipment with rehabilitation will likely receive more customers due to better user experiences stemming from gamification. Additionally, the CEI statistic that 86 percent of adults will willingly pay more for a better experience supports the idea that clinics should provide AR equipped technology for customers (Wolfe, 2012, para. 4).

Technologies such as new telerehabilitation platforms and other affordable methods of physical therapy are designed to provide patients with custom physical therapy exercises. Spark, an existing AR physical therapy platform, is designed to help clients who suffer from musculoskeletal injures (FG Team, 2018). The implementation of AR within these new technologies means that engineers and healthcare workers can collaborate to improve on existing designs in order to develop better features for patients under physical rehabilitation. Spark itself incorporates a smart interactive floor and wall mounted projectors to provide a screen to simulate its game-like exercises. By being flexible with its ability to create custom exercises in accordance to patients' needs, the platform is able to cover a wide range of clients.

Spark's use of projectors is a large factor for its flexibility and customization. The visual projectors provide feedback to the user in order to correct patients if they are performing the exercise incorrectly, even going as far as providing suggestions for improvement in future exercise sessions (FG Team, 2018, para. 3). The platform is also capable of providing therapists with real-time feedback on any pain that the patient feels, allowing for proper adjustment under remote supervision should the patient choose to perform this within their own home. Spark helps track the patient's efficiency and consistency in keeping with their scheduled exercises while constantly working to shape it to make the routine more personal (FG Team, 2018, para. 4). While the technology platform has been created, it has not been widely distributed despite its affordability. However, Spark provides a perfect system of a working AR technology that helps patients with physical rehabilitation. Although Spark has not been commercialized, the goal is for a practical, affordable version of technology that will adequately provide an effective means of ensuring that patients follow their physical rehabilitation program while receiving proper feedback from their therapists.

THE AR NETWORK IN PHYSICAL REHABILITATION

Once existing technical trials using augmented reality come to a conclusion, then new methods of enhancing the physical rehabilitative process can be introduced. The experimental technology that interjects during existing rehabilitative processes in many case studies looks for ways to improve clinical outcomes for physical therapy. An active method concerning therapists is communication. Traditional physical rehabilitation often requires that patients make frequent checkups with their doctor to assess the recovery progress. Remote guidance is limited and thus, suggests an area needing improvement. Existing frameworks for physical therapists to

communicate with their patients can instead be implemented using subsystem networks as seen in Figure 2.

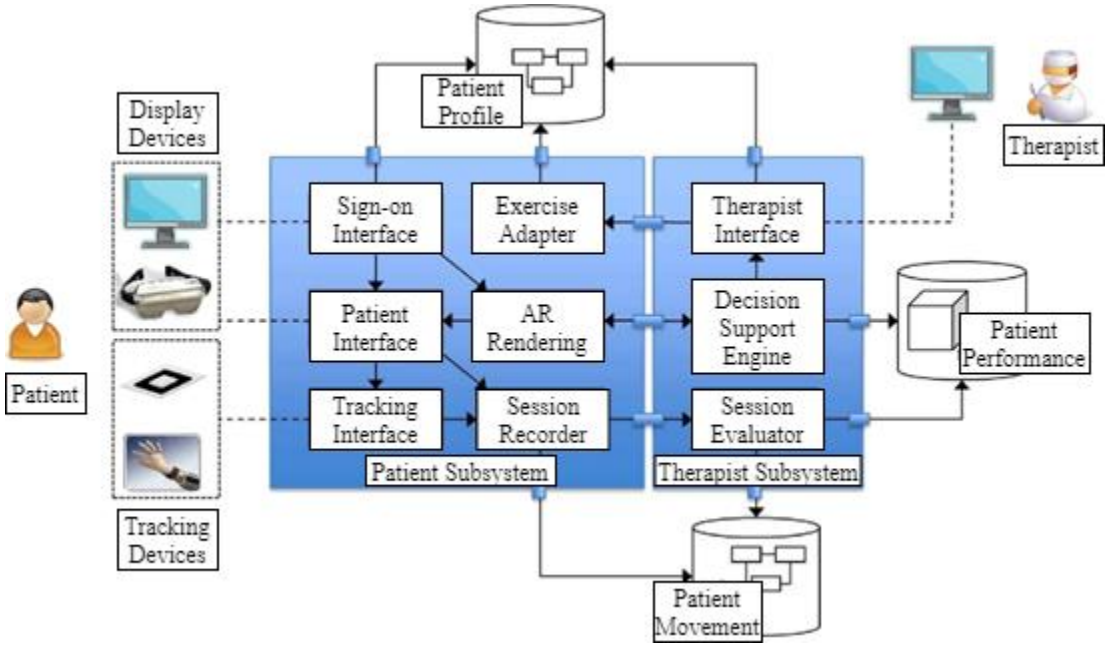

Figure 2: Patient Therapist Subsystem Framework: The architecture displays how therapists can effectively monitor and remain updated on their patients' recovery progress while maintaining remote communication (Alamri et al., 2010).

While the equipment pictured in Figure 2 shows physical tracking devices among them, AR does not necessarily require them as a camera lens is generally all that is needed in order to match users' actions to the simulated visuals. Although the tracking devices themselves are not entirely meaningless, the additional equipment is expected to increase the overall cost for patients and potentially cause issues if improper movement tracking is recorded.

In researching various sources related to AR and physical rehabilitation, two STS frameworks were used to conduct analysis. The main frameworks which were used for interpretation consisted of the social construction of technology (SCOT) and Actor Network Theory (ANT). The SCOT framework can be traced to Trevor Pinch and Wiebe Bijker's theory that claims scientific knowledge is determined mostly through social forces that are largely independent of one another (Klein & Kleinman, 2002). Through SCOT, the main issue that

addresses AR from this framework is the existing pretext of knowledge that people have surrounding it (Detel, 2001). Many people have little experience with related products, with the mainstream ones being Google Glass and, very briefly, Pokémon Go.

There is an inadequate amount of social communication about AR, which can largely be attributed to its infancy as a technology. While the association of visuals and wearable technology is an accurate display of the contents of AR within physical rehabilitation, it is not a topic that is otherwise conceived of in general. For this reason, one of the downsides of SCOT is its problem concerning the objectivity of knowledge, as researched by Saila Anttonen, a professor within the Department of Education at the University of Oulu, in a paper presented at the 1999 European Conference on Educational Research (Anttonen, 1999, para. 2). The reliability of existing constructs of knowledge is questioned when bringing AR into the healthcare field as new knowledge constructs are created in order to cast aside doubt from the feasibility of implementing AR for rehabilitative purposes. However, by looking at examples of cases where different technological platforms have begun to experiment and incorporate AR into the physical therapy practice, it reinforces the idea that a paradigm shift within the existing construction of knowledge can occur. Since people are guided by the interactions stemming from the environment around them, the percentage of individuals with relations to aspects of physical rehabilitation is an uncommon amount. By using the SCOT framework, the analysis of AR in physical rehabilitation works to determine the potential of the technology in paralleling other healthcare innovations while also presenting certain challenges that AR faces from easily cementing itself.

Actor Network Theory is a theory developed by Bruno Latour and Michel Callon with the core assumption that technology is a large factor that configures how society is shaped as

time moves forward while placing various levels of importance on the things within a network (Callon, 2001). With ANT, the web of relations that connected with physical rehabilitative services and AR alike formed the network of factors that were considered for analysis. Under ANT's main assumption, the same approach is used to assess AR's implementation for healthcare purposes. In determining the path that is the most feasible for widespread implementation, many branches stemmed from the aspects of physical rehabilitation. Cost of equipment, patient engagement, customer satisfaction, and business incentives are all inherent factors that are part of the broader network surrounding AR. Actor Network Theory also helps to categorize the importance of the actors within this network, as mentioned in part of a paper written by Andrea Whittle, a professor at Cardiff Business School (Whittle, 2008). The categorization helps to place emphasis on the roles of more important factors, which demonstrate the benefits that AR brings to physical rehabilitation. While some of the actors are tangential, such as business incentives, they are relevant nonetheless in the analysis of factors that affect the implementation of new technology. The less prominent actors are analyzed through this framework because a lack of regard for them fails to cover for the notable variables that affect real world interactions with emerging technological feats. By taking them into account, the analysis conducted on each individual aspect strengthens their connection with the actors of higher importance, which in turn reinforces the benefits that AR brings for physical rehabilitation.

AUGMENTED REALITY MOVING FORWARD IN REHABILITATIVE SERVICES

From the research conducted on the methods and factors that AR influences to benefit physical rehabilitative services, the judgment is that with successful implementation, then patients will thoroughly see an increase in engagement, leading to positive health improvements.

The purpose of this research paper is to present the various factors that affect AR's integration with physical rehabilitative services as the technology has not yet evolved to become a widely commercialized method of treatment. While many parallels to existing technology were made to represent the path that innovation with AR may foresee, there remains the limitation of experimenting with a widespread use of AR equipment in physical therapy over a long period of time. Since certain scenarios require additional data from ongoing studies that will conclude in the future, the analysis in this paper serves as a guiding point for presenting the various factors that help contribute to successful implementation of AR for patient care in rehabilitative services. Future work is necessary to provide the general populace with a concrete, disclosed blueprint of new price figures for the incorporation of AR and for patients themselves to determine the usefulness of the technology in keeping engagement levels high for the foreseeable periods after implementation.

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