Introduction to Augmented Reality (AR)

Augmented reality (AR) is technology that is based on the seamless integration of real and virtual worlds by superimposing computer-generated virtual elements on a view of the real, physical environment such that the virtual content can be perceived and interacted with in alignment with the reality of the user in terms of the actual physical location of real persons and objects (Azuma, 1997). AR can be differentiated from virtual reality (VR). Digitally produced elements are blended into a real-life display of the user's physical environment in AR-based applications, but VR-based applications display only virtual content such that users have to depend on their imagination to completely recreate the environment. In simple terms, a VR visual display totally replaces what a person sees in the actual environment whereas an AR visual display adds (or supplements) graphical or informational content to what a person can actually see in the real world so as to enhance situational perception. AR therefore is not as mentally complex as VR. AR has greater proprioceptive feedback than VR, is safer due to increased awareness, and allows tangible interaction with objects and the environment (Gil et al. 2021). "VR blocks out the real world (reality) and replaces it with a fully virtual (digital) world...AR does not block out reality but it adds computer-generated content onto the real-world experience" (Loia & Orciuoli, 2019).

Introduction to AR Rehabilitation

One of the newest domains for AR applications is the rehabilitation technology industry. AR applications can be employed to gamify traditional fitness workouts to make physical exercise more enjoyable and fun to all age groups and fitness levels. Therefore with access to AR-enhanced rehabilitation activities, individuals with rehab and exercise needs are more likely to take up therapeutic exercise whereas more active persons may become more engaged during exercise, with both groups being more likely to have the motivation to commit to more exercise hours and adopt a therapuetic exercise regimen or participate in rehab program for longer periods of time. These observations on activation of pro-movement behavior and persistence in its adoption are grounded in scientific principles of human motor learning and performance, movement science, as well as theories concerning intrinsic motivation, self-determination, and self-efficacy as detailed in the following sections.

The Benefits of AR "Equipment"

By providing a virtual representation of exercise equipment or therapeutic implement, AR applications enable users to have the convenience and cost advantage of having a visual target that can be configured or set up flexibly in numerous ways anywhere in their real surroundings, almost instantly, and without having to actually move physical objects or involve a costly investment in different types of training hardware. This computer-generated, virtual equipment or implement can serve as an external cue that the AR user can focus on during actual physical movement to better achieve the intended action goal. Substantial research evidence has accrued favoring the use of an external focus (EF) of attention by concentrating on the intended movement outcome (e.g., reaching the location of the virtual target) over the use of internal attentional focus by thinking explicitly about how a body part is moving (e.g., straightening the elbow), for a person to learn a movement skill or perform an exercise routine with greater effectiveness.

The benefits of AR-based external focus may include: shorter movement time for completion of more repetitions within a fixed duration so that a greater amount of therapeutic exercise workload can be achieved in a shorter time, greater movement accuracy, improve movement efficiency, higher levels of aerobic endurance, increased stamina to increase physical workload, and greater force production with lower neuromuscular activation so that a higher intensity can be achieved within a rehabilitation session (Chua et al., 2021). The advantages of using EF to learn or perform movements are present regardless of age, health status, and experience (or skill) level. This would mean that the barrier to start exercising and continue participation on a regular basis could be lowered for anyone who is interested in improving their physical function by using AR-enhanced equipment and the external focus benefits that it provides.

External Focus Features in AR

AR applications can provide virtual elements either as stationary reference locations that are superimposed on the real environment of users that they can use as EF cues, or as dynamic reference points that users can see moving in tandem with specific body parts of their bodies, which they can also use as EF markers without having to think about those body parts and hence, be able to avoid the downfalls of using an internal focus of attention while practicing a movement skill or exercising. On-body markers referenced as EF cues had been shown to enhance movement form and aspects of physical performance from children (Abdollahipour et al., 2015) to adults (Chua et al., 2018). The beneficial implications are higher levels of skillful movement, more explosive power, and greater postural stability in therapeutic exercise settings. Both the constrained action hypothesis (McNevin et al., 2003) and the self-invoking trigger hypothesis (Wulf & Lewthwaite, 2010) have been proposed for explaining the automaticity mechanisms underlying the advantages of using EF versus the detrimental effects of focusing inwardly towards the self on human learning and performance of skilled movement for participation in sports, exercise, and other rehabilitative physical activities.

The Benefits of AR in Motor Learning

According to the Optimizing Performance Through Intrinsic Motivation and Attention for Learning (OPTIMAL) theory, goal-action coupling is also enhanced when a person is able to direct attention solely on the intended movement effect or outcome, and not on how a body part is moving or how various body parts are coordinating (Wulf & Lewthwaite, 2016). AR applications can provide salient stimuli to assist the user with movement planning, execution, and feedback processing by overlaying virtual content pertinent to the user’s movement goal (or preferred type of graphical icon) on a visual display of the real environment that the user is already situated in.

With this approach, the user can be assisted in focusing attention fully on the computer-generated task element(s) guiding the action towards achieving the movement goal (e.g., target location, implement trajectory, overall movement pattern) without the undue cognitive burden of having to mentally process an unfamiliar environment (such as when all or most of the content on the visual display is virtual). AR applications that are capable of real-time mapping and display of movement information as augmented feedback (to supplement task-intrinsic feedback acquired through the user's own sensory system) can also enable the user to have instantaneous and continuous access to knowledge of performance (Gentile, 1972). In the teaching of motor skills, AR has been compared to face-to-face instruction, showing that there was no reduction in error or time to completion when performance was measured to assess the retention of skills 24 hours and 7 days after the instruction was given (Chinthammit et al., 2014).

Other extrinsic information such as movement speed and movement accuracy converted to performance scores, which can be automatically processed by specially designed operating algorithms of AR applications and displayed in an accumulative manner while the movement activity is ongoing or cumulatively upon the completion of the movement activity, relative to the movement goal, can allow the user to gain knowledge of results (Salmoni et al., 1984). These forms of augmented feedback, applied in isolation or in combination, can provide an information-rich therapeutic exercise environment for effective guidance of a person's movement pattern in producing the desired movement technique and/or achieving the predetermined movement goal (Lauber & Keller, 2012; Oppici et al., 2021), which may improve functional movement outcomes by accelerating the users' learning rates as well as their adherence to therapeutic exercise programs. These sources of movement-related information can be valuable in enabling a person to achieve rehabilitation sessions of higher intensity levels while minimizing movement-related injury risks. A systematic review of 32 research studies found that AR applications, both game-based and non-gamified, have usability potential for correcting, improving, and optimizing movement through the use of richer sensory feedback given via auditory, imaging, and/or textual modalities (Cavalcanti et al. 2019). Smaller studies have found that AR applications may be twice as effective at improving learning and short-term retention of movements when compared to traditional video demonstrations (Anderson et al., 2013).

The Effects of AR on Autonomy and Psychology

Not only are virtual elements in AR applications useful as EF visual cues for guiding movement along desired trajectories, to form an efficient pattern of coordination, or to project an object towards a predetermined end point (e.g., target location), they can provide a versatile medium through which users can easily have control over the task conditions in their preferred exercise environment. As virtual elements can be easily generated in myriad ways by AR applications, users can perceive themselves to have autonomy when they are able to choose specific program features that they like. Autonomy support is an evidence-informed motivational factor that can be used to optimize motor performance and learning (Lewthwaite & Wulf, 2017). As it has been found that autonomy-support approaches are effective in increasing physical performance and the explosiveness of movement, for example, during jumping, such applications may allow for AR-rehabilitation applications to increase the user's energy expenditure and improve measures of their functional performance.

Moreover, AR applications can be specially designed to allow users to choose the color and/or shape of the workout area to be overlaid on a visual display of their physical environment (Chua et al., 2018). Depending on the preferred exercise difficulty level and/or setting, users can even choose from a wide variety of thearpeutic exercise programs in terms of the type of desired outcomes and therapeutic goals, types of video delivery (e.g., live group fitness class versus pre-recorded, on-demand individual fitness session), and types of instruction (i.e., real-person talking head, avatar coach, or no instructor). We can also draw inspiration from Wulf et al.'s (2017) use of different colored mats for designing AR-based rehabilitation applications that allow users to choose specific properties of virtual elements that are aesthetically appealing to them so as to enhance their learning of movement skills while enabling them to experience more positive emotions.

Using AR to Achieve Exercise Recommendations

According to guidelines from the WHO, adults between the ages of 18 and 64 should have at least 150 to 300 minutes of moderate-intensity aerobic exercise or physical activity, or participate in aerobic exercise or physical activity with an accumulated time of at least 75 to 150 minutes at the vigorous intensity level, or an equivalent combination of both, per week (Bull et al., 2020). In addition, there should be at least two days of moderate- to high-intensity muscle-strengthening exercise or physical activity involving all major muscle groups each week. In addition, neuromotor exercises, or those that include coordination, proprioceptive demands, and skill-learning, are recommended for physical and brain health benefits. AR-based exercise interventions can combine aspects of aerobic, strength and neuromotor exercise modalities into potentially effective, multimodal exercise programs guided by AR-elements. Research-based evidence for the health benefits of regular exercise and a non-sedentary lifestyle are well established (Anderson & Durstine, 2019; Vina et al., 2012). These benefits include lower risk for chronic diseases, clinical depression, stress, and dementia as well as improved cardiorespiratory fitness, bone health, brain health, mood, self-esteem, sleep quality, and health-related quality of life. According to a review by Gil et al. (2021), implementation lengths of AR exercise interventions typically range from 20 to 30 minutes per session, are conducted approximately three times per week, and each intervention has an average of 12 sessions. Rates of adherence in AR interventions have been high, ranging on average from 95 to 100% (Gil et al., 2021; Tunur et al., 2019). Given these average durations and rates of adherence, AR fitness interventions may be effective for achieving and adhering to the minimum recommendations for exercise, including in rehabilitation programs, that are beneficial in the prevention and management of a variety of health-related conditions.

AR Rehabilitation for Increasing Exercise Adherence

Multiple factors contribute to a low level of participation in regular exercise or the lack of a physically active lifestyle. An estimated four in ten adults are physically inactive because they do not find physical activity to be enjoyable (Hoare et al., 2017) or interesting (European Commission, 2018). The gamification of exercise via AR applications can overcome this barrier by making physical activities engaging and fun so as to foster an approach-oriented style of coping rather than exercise avoidance. Taking the exemplary popularity and success of AR-based games involving physical activities, AR applications for implementing gamified exercise programs can promote intrinsic motivation (due to inherent satisfaction gained from participation that users perceive as enjoyable, fun, and interesting) that results in greater investment of efforts and higher commitment to regular exercise. Kosoris et al. (2015) found that a mobile application containing AR game elements was not only preferred by users over another game application with neither AR elements nor connection to the users' real world, but was used approximately ten times more. "AR solutions which encourage physical activity and participation (by incorporating geolocation technology and other solutions) promise to supplant common sedentary activities such as television watching, internet surfing, and the playing of static video games" (Poku et al., 2017).

The initiation and maintenance of long-term exercise adherence can also be facilitated by enhancing users' perception of self-competence, personal autonomy, and social relations with others. The self-determination theory established these three factors as basic human psychological needs (Deci & Ryan, 2000; Ryan & Deci, 2000). Moreover, Bandura (1977) hypothesized that a person's self-efficacy serves as an intrinsic modulator of behavior with regards to initiating action and persisting in activities when faced with adversarial or challenging situations. AR-based therapeutic exercise programs that can provide users with instructions and feedback that affirm self-efficacy in effecting program success, autonomy in choosing user preferred program features, and opportunities for positive social interactions with other program users, are likely to have a motivational effect on user experiences. Along this line, the OPTIMAL theory also predicts the motivational benefits of enhanced expectancies (through success-affirming instructions, manipulation of the task environment to potentiate accomplishments, and positive feedback) and autonomy support (via task-related or incident choices) for movement-related outcomes (Wulf & Lewthwaite, 2021).

Further Benefits of Autonomy and Social Support in AR Rehabilitation

Visual AR cues can be used to promote the perception of a lower task difficulty, such as a target that can be perceived to be bigger than its actual size, can help novices to experience higher levels of self-efficacy as well as greater learning outcomes (Chauvel et al., 2015). Individuals who received positive informational feedback, in the form of knowledge of results that emphasized good-performance trials over bad-performance trials, reported higher levels of intrinsic motivation in terms of perceiving themselves to be more competent at performing a given movement task

(Badami et al., 2011) or experienced higher levels of confidence in task success in addition to enhanced retention of movement skills after practice (Saemi et al., 2012). Besides learning benefits, self-efficacy has been shown to be positively correlated with the performance of sport skills (Moritz et al., 2000). Research participants who were allowed to choose the order of which they would like to perform four exercises voluntarily completed more repetitions across all four exercises than those who were not given such a choice (Wulf et al., 2014).

When AR applications are designed to include a social platform that enables interaction with movement professionals (such as physical therapists), exercise groups, and other individual users, users can receive expert and peer support, which in turn can result in greater engagement during program participation as well as heightened motivation to adopt a prohealth attitude. Individuals who were given instructions in a research study indicating that the researcher acknowledged, cared, and were interested in their learning experiences performed movements more effectively and increased learning outcomes, as compared to others who were shown disinterest by the researcher or did not receive any social-relatedness treatment (Gonzalez & Chiviacowsky, 2018). As highlighted by Dr. Bailenson in an interview on social interaction involving AR, "*We've discovered that using augmented reality technology can change where you walk, how you turn your head, how well you do on tasks, and how you connect socially with other physical people in the room*" (Shashkevich, 2019, para. 3).

The Physical Benefits of AR in Rehabilitation

AR-enhanced interventions have been shown to achieve rates of program adherence as high as 95-100% (Gil et al., 2021; Tunur et al., 2020). Moreover, research surveys showed that higher usage of applications employing AR technology was associated with a higher level of physical activity, in terms of instrumented measurements of duration and intensity of exercise (Althoff et al., 2016; Howe et al., 2016; Marquet et al., 2017; Marquet et al., 2018), or as self-reported in terms of frequencies and duration of physical activity participation (Nigg et al., 2017; Wong, 2017), especially for those considered to be less physically active prior to becoming users (Ma et al., 2018; Xian et al., 2017). Relatedly, users of AR applications spent less time in sedentary behavior than non-users (Khamzina et al., 2020; Nigg et al., 2017;). Additionally, the research synthesis of 36 research studies revealed that users of AR applications not only increased daily physical activity and had higher total numbers of days participating in moderate-level physical activities, but also reported greater improvement in psychosocial well-being than non-users (Lee et al., 2021).

Besides the motivational effects of AR-implemented exercise programs, do they also have real benefits for the improvement of a person's physical fitness? Indeed, AR-enhanced therapeutic exercise programs involving resistance, aerobic, flexibility, and balance exercises were shown to be effective in increasing joint strength and range of motion, building skeletal muscle mass and enhancing its quality, as well as improving multi-item fitness test scores, static balance (with and without vision), gait parameters, falls efficacy, and exercise self-efficacy in elderly women (Jeon & Kim, 2020; Lee et al., 2017; Yoo et al., 2013). Exercise-based game applications utilizing AR technology have also been known to improve overall endurance and stamina, gait and running endurance and speed, as well as promote weight loss, decrease in body fat, and increase in muscle mass with no weight gain for users belonging to various age groups (Wang & Skjervold, 2021). Users had also reported improvements in their mental health (Ellis et al., 2020; Wang & Skjervold, 2021). Certain AR interventions have been found to increase an individual's average level of physical activity, heart rate, exertion level, strength, physical performance, and a sense of engagement when compared to non-AR interventions (Ahmad, et al. 2021; Gil et al. 2021; Al-Issa, et al. 2013; Ng, et al. 2019).

While there is clear demonstration for AR-based exercise technologies to improve functional outcomes, improve motor learning, increasing the adherence to and the enjoyment of rehab interventions, and harness the benefits of external focus, augmented feedback, autonomy support, and social relatedness, more research is needed to better understand these effects in a rehabilitation setting. In addition, more practically-designed AR rehabilitation applications are needed to be developed in order to better understand the role of such interventions in real-world settings, as opposed to the restricted use of AR prototype applications in research settings.

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