Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation

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Aims/background: Off-the-shelf games for consoles such as the Nintendo Wii, Nintendo WiiFit and Sony PlayStation 2 EyeToy have been developed and tested for the purpose of entertainment. Many clinics are adopting the use of these off-the-shelf devices for exercise, social interaction and rehabilitation because they are affordable, accessible and can be used within the clinic and home. Our group carried out initial usability evaluations for these off-the-shelf games and a prototype game (using an off-the-shelf device) specifically developed for people with disabilities.
Methods: A series of studies have been undertaken through formative and summative evaluation and focus group research with a sample of people recovering from spinal cord injury, traumatic brain injury and stroke. Findings from two studies are presented. Following a demonstration and trial of the devices, observational and questionnaire data were collected to determine participants' perception of each system's usability, appeal and enjoyment.
Results: The first study involved evaluation and focus group discussions of seven participants (two females, five males) with SCI (n=4) and CVA (n=3). Findings indicated that interaction with the EyeToy interface appeared to be more intuitive than the use of the Wii-mote interaction device, although some participants had difficulty navigating the menu of the PlayStation EyeToy. The second study involved evaluation of six participants (SCI=4 males, TBI=1 male, CVA=1 female), aged between 25 and 58 years. The investigator was able to increase or decrease the difficulty of a game (developed specifically for bimanual rehabilitation task), using an off-the-shelf haptic feedback device, for each participant, depending on their skill level so that each participant was able to work at a level that was challenging to them. In both studies, participants reported that they would be more motivated to exercise if playing these types of games in both the clinic and home setting.
Conclusion: This series of usability tests is the first phase within a program of work using gaming for a range of physical disabilities. The use of virtual reality and video games for rehabilitation offers potential for motivating patients to perform specific therapy tasks.

Keywords: Virtual reality, video games, rehabilitation, physical therapy, usability

Introduction

The primary goal of rehabilitation following spinal cord injury (SCI), traumatic brain injury (TBI) and stroke is to promote a maximal level of recovery of function while pushing the confines of physical, emotional, and cognitive impairments. Full reintegration into the community and vocation are the ultimate goals. Individuals with access to intensive multidisciplinary rehabilitation programs demonstrate earlier and faster functional gains on functional

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independence measures and shorter hospital stays.[1,2] Given the vast array of impairments associated with SCI, TBI and stroke, the rehabilitation community is challenged with providing high quality evaluations, and interventions at a reasonably affordable price.

The estimated number of people in the United States with SCI is 300,000 with approximately 12,000 new cases each year.[3,4] The average estimated lifetime costs directly attributable to SCI vary between $3 million and $7 million, depending on severity of injury. Of the three million Americans who suffer nonfatal TBIs each year, it is estimated that 90,000 will be left with lasting disability.[2,5] The Centers for Disease Control and Prevention estimate that at least 5·3 million Americans currently have a long-term or lifelong need for help to perform activities of daily living as a result of a TBI.[4,6] Direct medical costs and indirect costs such as lost productivity are estimated at $60 billion in the United States and the lifetime costs for one person surviving a severe TBI can reach $4 million.[4,7] Stroke or cerebrovascular accident (CVA) is the leading cause of serious long term disability with approximately 795,000 people suffering one or more strokes each year.[8] Approximately $70 billion per year is attributed to health cost (direct and indirect) associated with stroke. With current treatments, persons with stroke are more likely to live, however, 90% are left with one sided weakness resulting in abnormal gait patterns and reduced independence with activities of daily living.[8,9]

The most effective means to improve neuroplasticity and subsequent recovery of motor function following injury or disease to the nervous system is through intense skillful practice.[10–12] Unfortunately, the level of intensity required to induce neuroplastic changes is far more than any one therapist could direct. With increasing medical costs, reduction in paid benefits, longer waiting periods, and a shortage of rehabilitation specialists, individuals with SCI, TBI and CVA are in need of low-cost quality home-based sensorimotor rehabilitation. Substitutes and adjuncts to contemporary therapies are being developed that incorporate virtual reality (VR) and video games for rehabilitation. These games offer a unique opportunity within a wide range of clinical research areas. Virtual reality and video game technology has the potential to improve upon real world tools by providing an objective measurement and the ability to assess and augment motor rehabilitation under a range of controlled stimulus conditions.

Video games and virtual reality as rehabilitation tools

The use of video games and VR systems for rehabilitation has expanded rapidly over the past few years. Early research in the area of VR systems to assist people to relearn how to move, suggests that VR game-based technology can be used effectively to improve motor skill rehabilitation of a range of functional deficits.[13–24]

Virtual reality systems demand focus and attention, can motivate the user to move, and provide the user with a sense of achievement, even if they cannot perform that task in the 'real world'. However, these systems tend to be one-off expensive devices limited for use in research clinics. Clinic and home-based systems need to be affordable and easy to set up, use and maintain, while still providing the most appropriate and accurate interactions so that the user can practise motor activities needed to foster transfer to the real world.

The recent release and world wide acceptance and enjoyment of Nintendo's Wii and WiiFit has provided significant examples for the notion that exercise can be fun, provided it is presented in a manner that is entertaining, motivating and distracting. The Nintendo Wii and Sony PlayStation 2 EyeToy have demonstrated promising results as a low-cost tool for motor rehabilitation.[25–28] Furthermore, by using these devices for exercise, individuals have anecdotally reported a high level of enjoyment by interacting and exercising with family members. The Novint Falcon was designed to potentially replace the traditional computer mouse as a game controller. This device sells for just under $200 and can be used in the place of a mouse with off-the-shelf computer games to enhance user feedback as well as 19 downloadable mini-games specifically developed by Novint. The controller revolutionizes play by providing haptic feedback (sensory feedback during gaming interaction) to allow the player to feel weight, shape, texture, dimension and force of the object, allowing for more 'natural' play. The device is different from the Sony PlayStation 2 EyeToy and Nintendo Wii because the movement range is limited to a 10 cm × 10 cm area.

Usability research

Usability testing is a method used to determine how easy an application or device is to use and to identify issues that must be addressed in order to improve the design and functionality of the application/device.[29] Usability can be defined by a number of components:

(i) learnability: how easy it is for users to accomplish basic tasks the first time they encounter the design;
(ii) efficiency: once users have learned the design, how quickly they perform tasks
(iii) memorability: when users return to the design after a period of not using it, how easily they reestablish proficiency
(iv) errors: the number of errors users make, how severe these errors are, and how easily they can recover from the errors
(v) satisfaction: how pleasant it is to use the design.[29–31]

Usability research can take many forms, depending on the scope of the device or application being tested, the level of completion of the device/application and the goal of the researchers (what do they want to learn about/from the user?). Usability research can include focus groups, task analysis, and user observation and surveys. User observation and surveys can take the form of heuristic, formative or summative evaluation.[29–32] A wide range of products, devices and applications undergo usability testing at a range of levels of development and upon completion. Participants are often assessed individually, reducing the risk of biased feedback often attributed to focus groups. Usability testing provides insight into how new users relate to the application/device on initial exposure. The usability of tools for rehabilitation remains relatively rare.

The use of focus groups to gain information about a product grew out of the commercial business and manufacturing environment. This type of focus group typically consists of three phases.[33,34] In the first phase, the researcher aims to gain understanding about the end-user or target audience. Typically the focus group coordinator is on a fact-finding mission to better understand how the end-user sees, understands and values a particular product. The purpose of the second phase focus group is to pilot test a prototype of the product being developed. Focus groups are a rich source of ideas and are useful in the early planning stages of development. The focus group members often test a number of different prototypes and compare and contrast each one. This information is typically used to help fine tune plans for the next phase of product development. Often designers are given feedback from the focus groups that is incorporated into the next prototype of the product. Lastly, after the product is in use for some time, a third phase focus group is helpful to evaluate the product and determine ways in which the product or program could be improved.[33] Focus groups can gather subjective responses and feelings from the user, however some researchers feel that interaction between participants within the group could reduce individual responses, biasing the data.[34]

A user task analysis is 'the process of identifying a complete description of tasks, subtasks, and actions required to use a system as well as other resources necessary for user(s) and the system to cooperatively perform tasks'.[32] A task analysis can consist of surveys, review of documentation, interviews and observation of the user. Survey techniques provide subjective evaluation of a device/product/application; however surveys rely on the participant's ability to recall events and actions. Surveys are easy to administer and can provide large sample sizes.[34,35]

Usability testing provides both subjective and objective data and comparison between the two, allowing researchers to determine if the users' subjective responses are represented in their actions. Heuristic evaluation requires the review of the application or device by an expert that can identify consistency and design on a fundamental level.[32] Experts are chosen based on the type of issues that need to be identified: design, content, efficiency, navigation and overall structure. Heuristic evaluations provide an opportunity for the design team to obtain the perspectives from people with expert knowledge that have not been involved in the development process. The core process is to ask experienced designers to work through the application/device, adopting as far as possible the viewpoint of a novice user.[29,36] Usability testing is useful at the beginning of a project, when the design team requires feedback regarding users understanding of the basic design concept, and at the end, to identify any low-effort, high-yield refinements that are still possible. Formative user evaluation is often performed during the development phase. Summative user evaluation is performed once the product/device has been available and used for a period of time.[29–32]

Usability testing and video games

Game design is becoming a critical area in the field of user-centered design. Specific methodologies are being developed to address game design principles such as providing an immersive environment, developing a sufficient challenge and creating a fun and entertaining experience.[37] Design principles often focus on game play, skill development, user instruction and tutorials, level of strategy and challenge, game/story immersion, game mechanics

a b c d

a EyeToy boxing; *b* EyeToy soccer; *c* Wii Golf; *d* Wii Bowling

Figure 1 Screen shots of games used in first usability assessment and focus group

and controller/keyboard. The level of difficulty and challenge of game play can encourage skill development, improve immersion and motivate further game play.[37,38] The balance between game play mechanics, interaction devices, narrative and level of challenge is important for maintaining player interest and providing a positive player experience.[37,38] This is perhaps even more important when using games for rehabilitation. The game must be easy for the user to understand and achieve the required goals, however the level of challenge must be appropriate to maintain interest in the game and motivate further play. The game mechanics and the interaction device must be achievable and accessible for the user.

Usability testing of video games for rehabilitation

Off-the-shelf games for consoles such as the Nintendo Wii, Nintendo WiiFit and Sony PlayStation 2 EyeToy have been developed and tested for the purpose of entertainment. The off-the-shelf video game consoles and games have been tested on a diverse audience, however, they were not designed as medical devices or with a primary focus of an adjunct rehabilitation tool. It is not known if requirements for individuals with disabilities were considered in the game design of many of the off-the-shelf games or gaming consoles.

In recent years, usability testing has been performed on VR devices developed specifically for telerehabilitation.[39–41] This work focused on the technical aspects of the system set-up, instructions and therapist and patient performance. Interaction, game play and game mechanics were not the main focus of these studies, however the research demonstrated the value of usability testing in this area.

The usability of any tool or system has to be viewed in terms of the context in which it is used, and its appropriateness to that context.[42] The International Standards Organisation definition of usability describes the context of use to include the users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used.[42] The concept of using off-the-shelf video games for rehabilitation alters the context in which these games are used significantly. Considering the context in which the product will be used provides a framework to ensure that all factors which may affect the usability of a product are considered.[42] Since these games were initially designed for entertainment, the game play mechanics are not entirely applicable to those with disabilities. Thus, there is a need to gain a better understanding of the qualities of the off-the-shelf games and gaming consoles before these devices can be approved as appropriate rehabilitation tools for people with neurological disabilities.

Findings from focus group and summative usability observations

Summative evaluation and focus group research was undertaken with a sample of people with SCI and CVA. The goals of this preliminary research were to identify and define the characteristics of off-the-shelf video game systems (Sony PlayStation 2 EyeToy, Nintendo Wii) that were most enjoyable, user friendly, and motivating for individuals with SCI and CVA. Following a demonstration, the participants trialled the EyeToy (boxing and soccer games) and the Wii (golf and bowling games). The games were chosen because they were thought to be intuitive for patients who may never have used the devices before and each game challenged standing or sitting balance without requiring excessive upper extremity range of motion (Fig. 1). The order in which the games were played was counterbalanced. Participants were observed during the session and were asked to complete a series of questionnaires (Likeability Questionnaire, Usability Questionnaire) regarding their perception of each system's usability, appeal and enjoyment. The Likeability and Usability questionnaires were based on standard questionnaires,[43] however changes were made to the wording of questions to be more specific to the games tested.

Observations made during the usability testing were noted and recorded by the investigators. Finally, participants took part in 2 hours of group discussion with the investigators regarding the devices, including a brainstorming session exploring potential changes to improve games for rehabilitation. Responses were recorded and grouped into themes of presence, feedback, interactivity, positive comments, negative comments, game play, graphics, audio and suggestions for improvement. The data collection session was completed within 4 hours. The demonstration and game play was undertaken in small groups, followed by the focus group with all participants.

The study involved evaluation and focus group discussions of seven participants (two females, five males) with SCI (n=4) and CVA (n=3). The mean age of participants was 55·42 ($\pm$5·77) years (Table 1). Through the questionnaire responses, participants indicated that they thought the devices were easy to use, well integrated, and easy to learn. Responses indicated that they felt confident using the devices and did not feel that the devices were cumbersome to use. However, five participants expressed the need for more practice or tutorial sessions before moving into the full game mode. Observations recorded by the investigators during the usability testing were that participants were able to understand and more quickly grasp the interaction requirements for the EyeToy boxing and soccer games compared to the Wii golf and bowling games. Interaction with the EyeToy interface appeared to be more intuitive than the use of the Wii-mote interaction device. Participants required more time to familiarize themselves with the Wii-mote device and four participants required cueing to assist with finding the correct buttons on the device. Observational findings indicated that some participants had difficulty navigating the menu of the PlayStation EyeToy, both physically (could not reach the top of the screen to select choices) and cognitively (difficult to navigate through menu tree – some participants could not find the games section immediately). In particular, those participants with an SCI had difficulty reaching up to the menu screen located at the top of the television screen when playing with the EyeToy games. This issue could be remedied by tilting the camera downward and thus the user would not have to reach as high.

During the focus group discussions, participants reported being motivated to exercise outside of physical therapy sessions within the clinic setting. However, participants reported that they would be more motivated to exercise if playing these types of games in both the clinic and home setting. The responses were neutral when asked if participants preferred characters that looked realistic (video images of themselves or others) or interacting with the games via an avatar. Participants reported not realizing how long they had been playing, and a sense of being distracted from their disability. One participant suggested that playing these games could improve 'boring exercise regimes'. Some participants reported enjoying, for the first time, the added dimension of receiving feedback and rewards while playing. They noted this especially with the EyeToy game in which the user saw a visual representation of his or her self on the screen. Further comments were that the EyeToy was thought more interactive than the Wii when considering the game play mechanics and overall body movements required. Participants were able to achieve tasks within the Wii games without performing within the required or expected range of motion for the task (participants could interact with the golf game with small flicks of the wrist instead of a golf swing). Five participants commented that being able to see themselves using the EyeToy whilst playing was helpful. Five participants enjoyed playing from a seated position, while two were able to stand and commented on the enjoyment and added challenge of standing whilst playing. Participants felt that having a somewhat unrealistic graphics objects to interact with, as seen in both the EyeToy and the Wii games, was helpful because it made the games seem more playful. However, participants stated that realistic graphics

Table 1 Description of participants

Subject number	Gender	Age (years)	Time since injury (months)	Diagnosis	Employed	Own computer	Play video games
C-1	Male	65	6	CVA-R	No	Yes	No
C-2	Female	49	21	CVA-R	No	Yes	No
C-3	Female	61	47	CVA-L	No	Yes	Yes
S-1	Male	53	120	SCI-C6/7 ASIA A	No	Yes	Yes
S-2	Male	55	71	SCI-C4/5 ASIA C	No	Yes	Yes
S-3	Male	50	12	SCI-T10 ASIA C	No	Yes	Yes
S-4	Male	55	42	SCI-C6/7 ASIA C	Yes	Yes	No

and an avatar that looked similar to themselves or a video captured image of themselves could be more beneficial, especially when the goal of the game was to create a very specific movement. Participants felt strongly that having their own avatar or being able to watch themselves on screen would be a useful feature when returning to a game on multiple occasions. However, participants suggested that the use of their own avatar for the Wii was not important when playing short one-off games. The group consensus was that although participants enjoyed creating avatars that looked similar to themselves (using the Wii), the avatar need not look disabled nor move in the game via a virtual wheelchair or with a virtual frame/walking aide. The use of first person view and third person view was helpful at different times within the game environment and no one view was considered more beneficial. Although the EyeToy does not provide haptic feedback, the participants 'felt' that they had made contact with objects in the game. The feedback from the handheld device of the Wii game was considered helpful. However, some of the movements within the Wii and EyeToy games were difficult to control and participants were often unsure if they had made the correct movement. Realistic sound and auditory feedback were thought to be helpful. Participants discussed how they would enjoy more cognitive challenge in the form of puzzles or game challenges other than the sport games trialled in the sessions. Participants wanted games that were 'easy to learn yet hard to master!'

Summative evaluations of off-the-shelf video games

Further summative assessment is currently in progress at Precision Rehabilitation, Long Beach, CA in the form of focus groups and observation of individual participants using the Nintendo Wii, Nintendo WiiFit and Sony Playstation 2 EyeToy. Observations are being recorded and analyzed (in terms of how the device is being used, which game is being played, any difficulties experienced by patient or therapist), and participants are being asked to complete a series of open and closed questions upon completion of game tasks. Preliminary findings have demonstrated a range of interesting findings and suggestions for development of games for rehabilitation. Initial interesting findings from the observational data suggest that therapists are not providing enough instructions. Instructions need to be provided, not only about the game but how patients can play the game with the therapeutic goal in mind.

Figure 2 Novint Falcon device

Some therapists have been observed watching the game play and not focusing on the patient. As with conventional treatment techniques, therapists need to observe the patient to determine if the patient is behaving in an appropriate and safe movement pattern. Finally, some games are providing negative auditory and visual feedback to patients that are performing tasks effectively because the patient cannot move fast enough for the game play or cannot perform all of the required movements within the game.

Formative assessment of prototype game developed specifically for rehabilitation

The Novint Falcon is an off-the-shelf game controller that provides realistic haptic feedback during gaming interaction (Fig. 2). When using this device, the player feels weight, shape, texture, dimension and force of an object, allowing for more 'natural' play. For example, if playing a ball catching game, the player feels the impact of the ball coming into contact with their hand. Once the controller comes into contact with the virtual object, the computer updates currents to the device's motor, resulting in a force applied to the handle that is felt by the user. The current in the handle is updated 1000 times per second. The device uses interchangeable grips and can move in three dimensions to interact with objects on the screen. This device can be used in the place of a mouse with off-the-shelf computer games to enhance user feedback as well as 19 mini-games developed by Novint. Participants initially trialling the device (playing a ball catching game), during a focus group/usability evaluation at Precision Rehabilitation in Long Beach, CA, reported that they liked the haptic feedback, however they found the device was difficult to grasp and did not feel like they were using their arm and body enough. In particular, participants with SCI felt that using the

Figure 3 Two Novint Falcon devices yoked together with a screen shot of the bimanual task

Novint Falcon restricted their movements more than the other games in which larger movements were encouraged. Comments were made by participants during the focus group session that the device provided the best feedback, however the game needed to be more related to therapy. Participants could not see the advantage in practising the ball catching task on the Novint Falcon device as part of therapy.

Based on the feedback gathered about the Novint Falcon from the focus group, changes were made to the system set up and game. Two Novint Falcon devices were yoked together to provide a low-cost device that required bimanual coordination to control (Fig. 3). This not only made the task more relevant, but added cognitive challenge to the task. To train bimanual coordination, a game was developed in Ogre3D (an open-source graphics rendering engine) using two Novint Falcon devices yoked together. The user can control a platform using the Falcon devices. The right device can lift or drop the right side of the platform and the left falcon can lift/drop the left side of the platform. The goal of the game is to control a block on the platform by sliding the block to the center of the platform and holding it within a target area for five seconds. The two devices must be used together to complete the task. The weight of the block can be altered separately for each device (one device could provide the sensation of less weight than the other). The friction of the block on the platform, the size of the target area and the time limit can also be altered, requiring more control to stabilize and hold the block within the target. A 'gun' attachment was used to provide a larger grip than the original 'ball' attachment.

Formative testing was performed on this bimanual falcon device to assess the usability of the yoked falcon devices and the applicability of the game within a range of patient groups (SCI, CVA and TBI). A sample of six participants (SCI=4 males, TBI=1 male, CVA=1 female), aged between 25 and 58 years were recruited. Four of the participants currently played video games. Three participants (SCI=2, CVA=1) owned a Nintendo Wii and played golf, tennis, and bowling games and one participant played limited arcade style games on a Sony PlayStation 3. The participants were identified by their therapists as having difficulty with bimanual tasks and/or weakness in their upper extremities. Participants were asked to play the game and complete a series of questionnaires and focus open-ended questions.

All participants were able to play the bimanual Falcon game effectively. Of the four participants with SCI, three participants could grasp the 'gun' attachment using tenodesis grip and one participant required assistance using bandages to secure their hands to the devices. The participant with CVA required assistance to grasp the device (hemiplegic hand only) using bandages. All participants stated they enjoyed playing the game. Five participants stated that they felt as if the game made them work as hard as they did in a therapy session and would like to use the game as part of their regular therapy. Each participant began the first set of tasks at the same level. The investigator was able to increase or decrease the difficulty of the game for each participant, depending on their skill level (by changing the weight of the block, friction of the platform or size of the target area). Each participant was able to work at a level that was challenging to them, however, one participant with SCI stated that the devices would need to be placed on a stand in a different position before he felt it was challenging enough to be useful for therapy.

All participants found the haptic feedback helpful in completing the game tasks. None of the participants felt they would be comfortable setting up the device without assistance. Each participant provided helpful suggestions for changes to the grip that would provide a more comfortable and accessible device. Participants also provided suggestions for improvements to the current game and ideas for other games they would like to play as part of therapy. The preliminary results of this research will be used to continue to develop and assess games for rehabilitation of upper extremity tasks using video game based bimanual training.

Summary

Just as new therapeutic devices must undergo assessment prior to integration into standard therapies, so too is assessment required when existing devices are used in a context beyond the scope of their original intent. Preliminary results from focus group and usability testing indicate that off-the-shelf video game devices could be well-received as rehabilitation tools. It is important that off-the-shelf games undergo analysis to determine if they contain appropriate content to focus on therapeutic goals within different patient populations. Specific and detailed tutorials should be provided to patients to ensure they can understand the device set-up, including turning the device on, menu navigation and selection and positioning of self and device. Therapists should ensure that patients are performing the tasks appropriately during the game. Care should be taken when choosing and teaching patients to use devices because some of our participants were able to play the games without performing the correct or required movement. Care should also be taken when choosing games because some games provide negative feedback that could be inappropriate for patients. Although the Falcon device and game developed by our group is different in a number of ways to the Wii and EyeToy devices and games, having the ability to make a game that can be easily modified by therapists for a range of patient abilities is likely to improve the usability of these off-the-shelf devices. The Falcon offers researchers the opportunity to develop games that provide haptic feedback and can be tailored to patient's needs and abilities, however, the device has a limited workspace area compared to the Wii and EyeToy. The Falcon is likely to be of benefit to a range of rehabilitation populations but is unlikely to take the place of the Wii, EyeToy or other interface devices that allow for larger and more natural movement patterns. Further development is required to ensure that each of these devices can be easy for patients and therapists to set up in the clinic and home setting. The small number of patients sampled within this early phase of our research has provided useful feedback and suggestions. However, more research is needed to determine the usability of specific video game consoles and specific games with larger samples of people with disabilities. Research is also needed to determine the effectiveness of the use of these games for rehabilitation.

Our group is continuing to assess the usability of off-the-shelf devices and games. We are also modifying and developing our own games to use with off-the shelf devices, based on feedback provided in focus groups. The purpose of developing games specifically for therapy is to provide the patient and therapist with more control over important aspects of the game and required motor skills. Our group is also developing our own low-cost sensor based devices (using camera based tracking, accelerometers, etc.) to interact with specifically developed games. The use of VR and video games for rehabilitation offers potential for motivating patients to perform specific therapy tasks. The popularity of this new breed of interactive devices such as the EyeToy, Nintendo Wii and Nintendo WiiFit has provided an opportunity for interdisciplinary research and development leading to the potential to improve clinic and home-based therapy for a range of impairments.

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