

Engagement Study of an Integrated Rehabilitation Robotic Tablet-Based Gaming System

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Abstract— Physical therapy is a common treatment for the rehabilitation of hemiparesis, or the weakness of one side of the body. However, a significant issue in the therapy process is that patients may struggle with motivation to complete the required therapy sessions. For this purpose, a rehabilitation gaming system was created that combines a hand rehabilitation robot with a gaming application on a tablet to promote engagement and discourage boredom. A study was also conducted to compare engagement between the gaming system and traditional therapeutic exercises. The results of this study show that participants prefer playing rehabilitation games more than they do exercising with traditional rehabilitation methods. On average, participants spent approximately four times longer playing the rehabilitation game before becoming bored than they did with traditional exercises. From their responses to the retrospective survey, the participants experienced significantly more enjoyment and engagement when exercising with the tablet game. They also experienced significantly less boredom. The participants unanimously agreed that if they were required to exercise their wrists for an hour a day, as is a normal requirement for patients in stroke therapy, that they would prefer to do so by playing the tablet game.

I. INTRODUCTION

Physical therapy is a common treatment for the rehabilitation of hemiparesis, or the weakness of one side of the body. Stroke is a common cause of hemiparesis [1]. Patients with stroke-induced hemiparesis may have reduced muscular strength to a vital body part, e.g. their dominant hand. However, through physical therapy exercises, patients can regain strength and improve their ability to use their dominant hand when performing daily activities. Unfortunately, physical therapy, in general, is a painful process that patients do not enjoy participating in. Furthermore, the attitude of the patient directly correlates to their compliance and success during physical therapy sessions [2]. Rehabilitation studies have shown that motivating and empowering patients by providing them with the perception of control can expedite the achievement of the patient's rehabilitation goals [3, 4]. Providing patients with positive feedback promotes morale and empowerment [5].

Last year, roughly 795,000 Americans suffered from stroke. This statistic is forecasted to increase. In America, stroke is also the leading cause of long-term disability [1]. Roughly half of these stroke survivors still suffer from hemiparesis six months after their strokes, and roughly 30% of stroke survivors were treated with outpatient rehabilitation [1]. A recent study found that about one third of stroke patients in rehabilitation hospitals are 'poor participators' as ranked on the Pittsburgh Rehabilitation Participation Scale

[6]. Thus, improvements upon outpatient stroke rehabilitation will benefit a large portion of our population. Additionally, about one third of stroke victims suffer from depression after their stroke [1]. Furthermore, the limitations caused by reduced wrist and hand movements are a key factor associated with reduced perception of quality of life [7]. Thus, stroke survivors will greatly benefit from morale boosting physical therapy.

In its current form, physical therapy is not enjoyable, causing patients to lack diligence in their participation at home [2]. Thus, a knowledge gap exists in how to make patients more accountable for their therapy. Not only do patients skip at home therapy due to lack of motivation [4], but, using traditional rehabilitation therapy, clinicians have difficulties in monitoring patient progress automatically while the patients are in their homes. Thus, in these traditional scenarios, clinicians typically do not know whether or not a patient has been participating in therapy until they come in for their next visit. And, even when the patient comes into the office, the clinician has few strategies for assessing patient diligence. The clinician will ask the patient how often they participate in therapy. However, patients may not answer honestly. The clinician can also assess the progress of the patient and extrapolate a guess of frequency of patient therapy sessions. However, if a diligent patient is progressing slowly, a low estimate made by the clinician about the frequency at which the patient is participating in therapy could further reduce patient morale [5].

Thus, a solution to these problems is to develop therapy gaming systems to monitor the frequency, duration, and physical motions of the patients during their at-home therapy sessions. These rehabilitation gaming systems have been shown to increase motivation [8] while maintaining similar treatment effectiveness [9, 10]. Game scenarios have been used in conjunction with robot-assisted rehabilitation devices to help motivate users through score keeping, where the score corresponds to the individual's achieved range of motion [8]. Custom-made virtual reality rehabilitation games with a robotic ankle orthosis have been shown to have more clinical benefits than the same rehabilitation in the absence of the games [9]. For patients with neurological gait disorders, a virtual reality robot-assisted therapy approach that induces a motor output is considered comparable to therapy sessions that utilize conventional approaches in the presence of a human therapist [10]. With respect to arm and hand movements in individuals with hemiparesis, an approach that utilizes different virtual reality tasks to provide a range of difficulty levels allows practice to be individualized by providing difficulty levels that are appropriately matched to each stage

of recovery [11]. The Gentle/s system has been shown as an appealing device that, when coupled with virtual reality technology, can provide robot mediated motor tasks in three dimensional space [12].

These systems are designed to engage patients through the use of interactive video games. These systems can also monitor the time spent in therapy and patient success in real time and provide feedback via game scores. This information can also be sent to clinicians in order to allow the clinicians to accurately track patient diligence and progress. It is hypothesized that these gaming systems can increase engagement and motivate patients to participate in longer therapy sessions. Thus, the purpose of this paper is to develop a robotic rehabilitation system that increases the engagement of its users.

II. REHABILITATION ROBOTIC TABLET-BASED GAMING SYSTEM

The system discussed in this paper has been specifically designed for stroke patients who are undergoing rehabilitation therapy for hemiparesis of the wrist. The hardware of the system consists of a Hand Mentor (version 2005), Asus mobile tablet, and additional circuitry [13]. These hardware components have been combined with a tablet gaming application to create an integrated rehabilitation gaming system.

A. Hand Mentor

Development of robot-assisted devices focused on improving hand function has increased in recent years [14]. These devices typically utilize repetitive tasks that are challenging to patients, allowing for improvements in upper-extremity outcome measures [15]. The robotic device selected for this research, the Hand Mentor, focuses on improving hand function by enhancing active range of motion of the wrist and fingers, while providing physical support for the wrist [16, 17]. Harnessing principles of motor learning, the device assists patients to perform repetitive activities using the robot platform. The system trains skills that are transferable to functional hand motor activities.

The Hand Mentor is an existing therapeutic device that consists of an arm brace, a McKibben muscle, and a control box, as shown in Figure 1 [17]. The device is capable of monitoring patient motion as well as activating an arm pump that is located inside the control box to stretch the wrist of the patient. This stretching technique is used in physical therapy to assist patients increasing their range of motion [18]. The device utilizes a pneumatic artificial muscle, known as a McKibben muscle, that is attached to the proximal forearm. Activation of the air muscle extends the wrist and fingers, causing the wrist stretching activity.



Figure 1. Hand Mentor arm brace (left) and control box (right).

B. Rehabilitation Gaming System Hardware

To enable interaction with a mobile tablet device, the electronics for the Hand Mentor were integrated with a microprocessor, a Bluetooth communication module, and a displacement sensor, as seen in Figure 2. The microprocessor, a Sparkfun RedBoard, was used to process the raw position data into a format that is useful to the tablet. The displacement sensor was attached to the Hand Mentor arm brace. The output from this sensor was read in by the RedBoard, packaged into a message, and forwarded to the Bluetooth communication module, the BT Board, which transmitted the message via Bluetooth to the mobile tablet device. The microprocessor first ran a routine that calibrated the central position of the wrist motions. Then, the z position of the displacement sensor was extracted. Finally, the displacement angle was calculated, which was transmitted to the tablet. This design was implemented to be compatible with a tablet, as Bluetooth is a commonly used form of data transfer between tablets and external devices.

C. Rehabilitation Application

To enable rehabilitation of hand function, the input to the rehabilitation game needs to correlate with the up and down motions of wrist movements. As shown in Figure 3, a tablet application entitled RoboBlaster was created for our rehabilitation game. In this game, the user moves the space ship, located in the upper left corner of Figure 3, up and down. The space ship does not move in the x direction; however, it fires lasers, not depicted in Figure 3, which travel in the x direction and collide with the asteroids. The objective is to shoot and destroy all of the asteroids in order to increase game score. Figure 3 shows that there are nine horizontal lanes, -4 through 4, that can be occupied by asteroids and the ship. The asteroids enter the playing field from the right side of the screen and move towards the left, while maintaining their y position.

The game accepts Bluetooth messages from the Redboard microcontroller containing the displacement angle of the wrist, which is then associated with the desired lane position of the space ship. The controls have been mapped such that an upward motion of the wrist inside of the Hand Mentor arm brace corresponds to an upward motion of the ship. Inversely, a downward motion of the wrist corresponds to a downward motion of the ship. The laser continuously fires, allowing for a simplified game control.

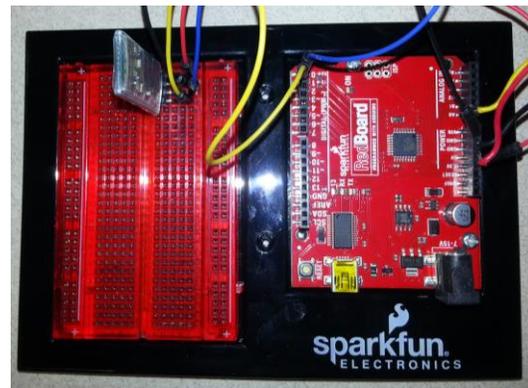


Figure 2. Electronics integrated with Hand Mentor device.

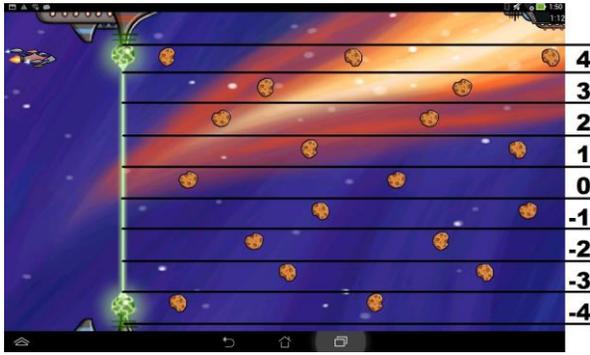


Figure 3. RoboBlaster stroke therapy game showing lane numbers.

TABLE I. MAPPING OF ANGLE RANGE TO LANE NUMBERS

Lane Number	Approximate Angle Range
-4	$-67.5^\circ \rightarrow -52.5^\circ$
-3	$-52.5^\circ \rightarrow -37.5^\circ$
-2	$-37.5^\circ \rightarrow -22.5^\circ$
-1	$-22.5^\circ \rightarrow -7.5^\circ$
0	$-7.5^\circ \rightarrow 7.5^\circ$
1	$7.5^\circ \rightarrow 22.5^\circ$
2	$22.5^\circ \rightarrow 37.5^\circ$
3	$37.5^\circ \rightarrow 52.5^\circ$
4	$52.5^\circ \rightarrow 67.5^\circ$

The arm brace flexes approximately 67.5° in the positive and negative directions from the central position. The recorded positions represent groups of angles such that the lane numbers correlate to the angle ranges shown in Table I. The value of the lane determines which horizontal lane, as seen in Figure 3, that the spaceship will occupy.

Audio files have been added to this game as well, to further motivate subjects. After destroying 4, 8, 16, 32, or 64 asteroids, a motivation message is played that congratulates the player on their progress and encourages them to continue with their success.

III. EXPERIMENTAL SETUP

For this study, 14 able-bodied participants between the ages of 14 and 35 were selected. Eight of the participants were male and six were female. The participants were asked to complete two tasks, wrist exercise with the tablet and wrist exercise without the tablet. Half of the participants were randomly selected to complete the exercise task with the tablet first and the other half completed the exercise task without the tablet first. The participants were instructed to end the exercise period when they became bored with the task. The time that each participant elected to spend performing each task was recorded.

Prior to beginning either task, the participants were put on the Hand Mentor arm brace and were told that they would be exercising with the arm brace. Immediately following the

completion of both tasks, the participants were asked to complete a survey that posed questions about the enjoyment and boredom during the two exercise tasks.

A. Exercise Task with the Tablet

For the exercise task involving the tablet, participants used the Hand Mentor controller to play the RoboBlaster game. A script was read to the participants prior to the initiation of the task. This script informed the participants that they would be playing RoboBlaster using the Hand Mentor as a controller. They were informed of the game play instructions and the goal of the game. They were also told to stop and inform the researcher when they became bored with the task.

B. Exercise Task without the Tablet

For the exercise task that did not involve the tablet, participants completed an exercise regimen that involved moving their wrist up and down while wearing the Hand Mentor. A script was read to the participants prior to the initiation of the task. This script informed the participants that they would be exercising with the arm brace by moving their wrist up and down. They were instructed to stop and inform the researcher when they became bored with the task.

IV. RESULTS

A. Duration

The average amount of time that the participants spent exercising is shown in Figure 4. As depicted, participants spent 222 seconds exercising with the tablet game and 59 seconds exercising without, on average. This difference equates to the participants spending roughly four times longer exercising with the tablet game than without the tablet game. While the standard deviation was high for both groups, 127.2 seconds and 41.1 seconds, respectively, an unpaired t-test resulted in a P value less than 0.0001, which asserts a statistical significance in the difference between these values, assuming a significance level of 1%. Therefore, participants spent significantly more time exercising when the regimen was accompanied with a tablet game than they did without.

B. Motions

Position data was recorded during the sessions. However, for the experimental sessions, a limited range of motion version of the game was used by the participants, as shown in Figure 5. In this version, the tablet game only produced asteroid targets in lanes -1, 0, 1, and 2.

The average percentage of time spent in each position during the tasks is shown in Figure 6 and the average movements are shown in Figure 7. While playing the tablet game, participants tended to make smaller movements and spend the majority of their time in the midline positions than they did without the tablet game. This limited range of asteroid placement that was used for this experiment explains why participants spent most of their time in the midline positions. However, these trends also suggest that rehabilitation games could be programmed to strategically place targets in a fashion that encourages participants to make specific types of movements, whether it be to move drastically from one position to another or to stretch and hold a specific position for a desired period of time.

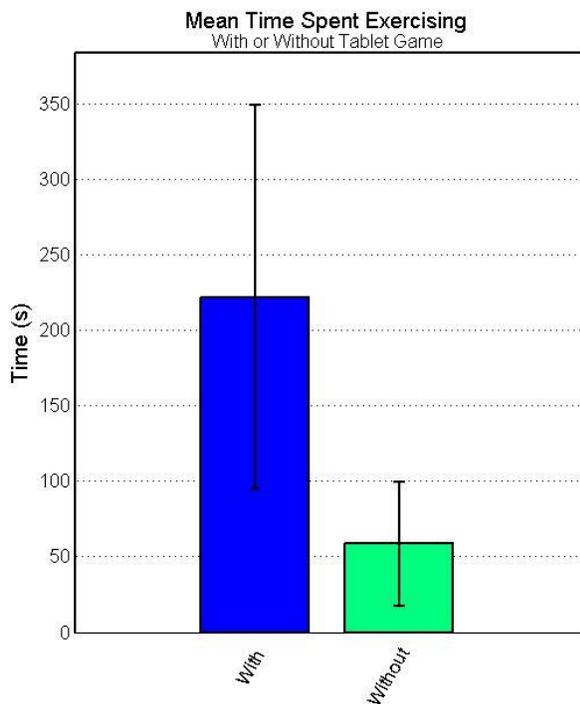


Figure 4. Mean time spent exercising with and without the tablet game.

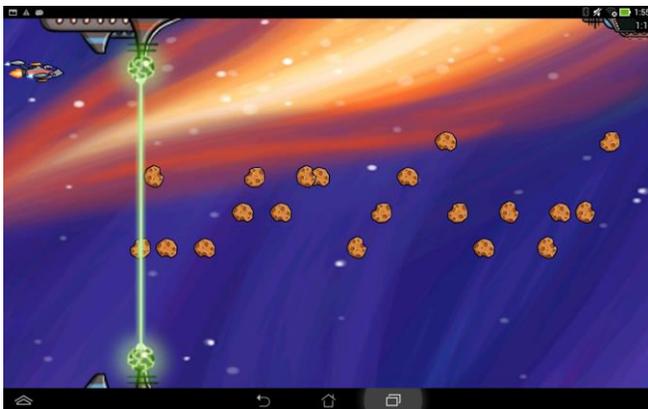


Figure 5. RoboBlaster game with limited range of motion only produces asteroids in lanes -1, 0, 1 and 2.

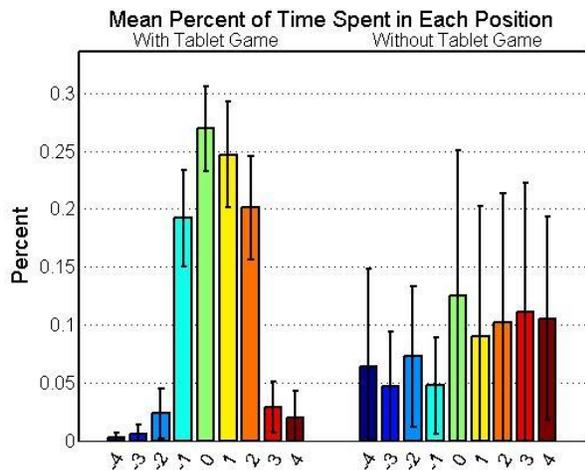


Figure 6. Mean percent of time spent in each position.

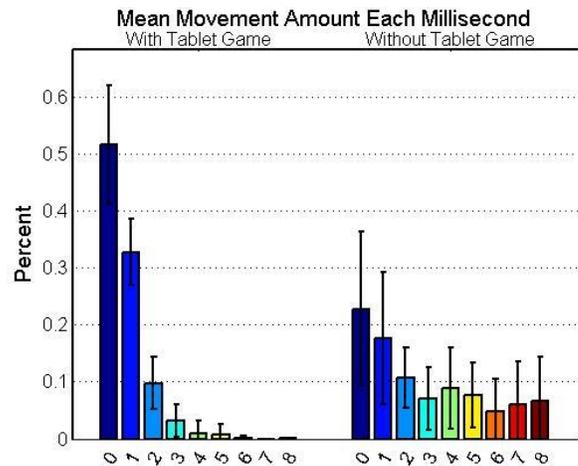


Figure 7. Mean movement measured every millisecond.

TABLE II. P-VALUES FOR THE MEAN PERCENT OF TIME SPENT IN EACH POSITION

Position	P-Value
-4	< 0.0001
-3	< 0.004
-2	< 0.009
-1	< 0.0001
0	< 0.0003
1	< 0.0001
2	< 0.005
3	< 0.02
4	< 0.002

TABLE III. P-VALUES FOR THE MEAN MOVEMENT AMOUNT EACH MILLISECOND

Difference	P-Value
0	< 0.0001
1	< 0.0002
2	< 0.58
3	< 0.028
4	< 0.0006
5	< 0.0002
6	< 0.005
7	< 0.007
8	< 0.005

Table II shows the p-values calculated from an unpaired t-test of the mean percent of time spent in each position. All lanes show a statistically significant difference in the percentage of time spent in the lane, assuming a 5%

confidence interval. Similarly, Table III shows the p-values calculated from an unpaired t-test of the mean movement amount for each time interval. All values of lane change per second, except for a value of two, show statistically significant differences between the movements that the participants made with the table game compared to their motions without, assuming a 5% confidence interval.

C. Engagement

Immediately following the completion of both exercise tasks, the participants were asked to fill out a survey, where they ranked a series of statements using a five-point Likert scale with selections ranging from one to five. On the Likert scale, one corresponds to strongly disagree, two to disagree, three to neutral, four to agree, and five to strongly agree. The following is a list of the statements that the participants were asked to respond to:

1. I enjoyed the exercise session WITH the tablet game.
2. I enjoyed the exercise session WITHOUT the tablet game.
3. Exercising was MORE enjoyable WITH the tablet game.
4. Exercise was MORE enjoyable WITHOUT the tablet game.
5. I felt that my exercise session WITH the tablet game was productive.
6. I felt that my exercise session WITHOUT the tablet game was productive.
7. I felt engaged while exercising WITH the tablet game.
8. I felt engaged while exercising WITHOUT the tablet game.
9. I felt bored while exercising WITH the tablet game.
10. I felt bored while exercising WITHOUT the tablet game.
11. If I had to exercise my wrist for one hour a day, every day, I would rather complete all of these exercises WITH the tablet game.
12. If I had to exercise my wrist for one hour a day, every day, I would rather complete all of these exercises WITHOUT the tablet game.

The averages and standard deviations of the participant's responses are shown in Figure 8. From the participant's responses, the participants experienced significantly more enjoyment and engagement when exercising with the tablet game. While participants gave high scores to enjoyment and engagement for sessions that were accompanied by the tablet game, they unanimously agreed that they did not enjoy the exercise experience without the tablet game. Participants also experienced significantly less boredom while exercising with the tablet game as compared to traditional rehabilitation exercises. The participants unanimously agreed that if they were required to exercise their wrists for an hour a day, as is a normal requirement for patients in stroke therapy [19], that they would prefer to do so by playing the tablet game. The participants also felt that their exercise with the tablet game was more productive than their exercise without, which would encourage them to participate in therapy longer and more frequently.

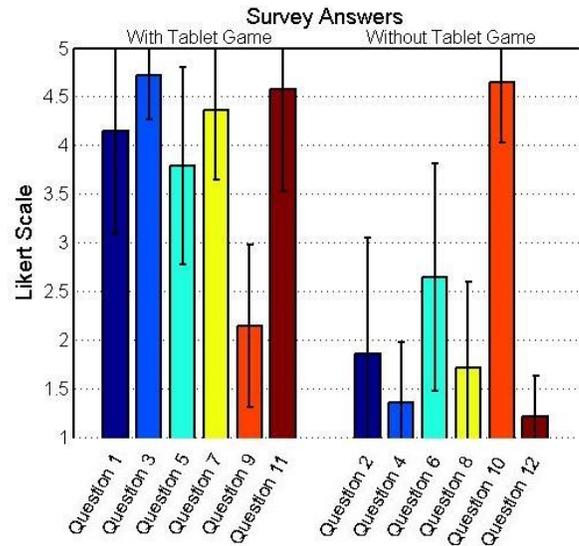


Figure 8. Mean responses to survey questions.

Table IV lists the p-values associated to each of the question sets. These p-values were calculated using an unpaired t-test. From the p-values in the first two question sets in Table IV, participants very significantly enjoyed the exercise experience more with the tablet game than without, assuming a significance level of 1%. As indicated by the p-value for questions #5 and #6, participants felt that the exercise experience with the tablet was significantly more productive than their sessions without, assuming a significance level of 5%. With a 1% significance level, question set #7 and #8 and question set #9 and #10 show that the participants felt very significantly more engaged and very significantly less bored while exercising with the game. Also, the p-value for the last question set indicates that participants would very significantly prefer to exercise with the tablet if they had to exercise for one hour every day, assuming a 1% significance level.

TABLE IV. P-VALUES FOR THE DIFFERENCE BETWEEN PARTICIPANT ANSWERS OF QUESTIONS WITH AND WITHOUT THE TABLE GAME

Questions being Compared	P-Value
#1 and #2	< 0.0001
#3 and #4	< 0.0001
#5 and #6	< 0.011
#7 and #8	< 0.0001
#9 and #10	< 0.0001
#11 and #12	< 0.0001

The least significance exists for question set #5 and #6. This could imply that the participants did not feel as though they were exercising when they were playing the tablet game, which could also be an encouraging factor to frequency and duration of exercise. However, this could also be explained by the game targets being grouped in the center of the screen, discouraging drastic movements. Therefore, strategic

placement of asteroids to encourage a more difficult exercise regimen could increase the difference between these scores.

V. CONCLUSION

The results of this study show that participants prefer playing rehabilitation games with the rehabilitation robot more than they do exercising with traditional rehabilitation methods. On average, participants spent approximately four times longer playing the rehabilitation game before becoming bored than they did with traditional exercises. From their responses to the retrospective survey, the participants experienced significantly more enjoyment and engagement when exercising with the tablet game. They also experienced significantly less boredom. The participants unanimously agreed that if they were required to exercise their wrists for an hour a day, as is a normal requirement for patients in stroke therapy [19], that they would prefer to do so by playing the tablet game.

VI. FUTURE WORK

Since this study has shown that participants were more engaged in therapeutic exercises with game stimulus, yet length of their engagement time could still be improved, a suite of robotic rehabilitation games is being developed. Such a suite will allow the users to select from variety of games, which we hypothesis will further increase engagement time.

In order to further explore the capability of encouraging specific therapeutic motions, asteroid placement algorithms will be added to the game. An experiment will be conducted in which participants play the game with the rehabilitation robot using a variety of asteroid placement algorithms. The results will be analyzed to see if the movements of the participants can be manipulated to encourage specific motions that would be most therapeutically beneficial. In future experiments, the control exercises will be better defined in order to allow for a more fair comparison.

The range of motion that the game encourages will be able to be adjusted via user input to fit the user's range of motion. This will allow the game to accommodate users at all levels of recovery.

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