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RESEARCH ARTICLE

Comparison of TrackMan Data between Professional and Amateur Golfers at Swinging to Uphill and Downhill Fairways

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Abstract:

Background:

Golfers face different environmental conditions in each game played under various constraints. Enhancing affordances through training in a constrained outdoor environment is crucial.

Objective:

To analyze club head behavior at ball impact of a tee shot by 42 professional (PGs) and 25 amateur (AGs) golfers in swinging to uphill and downhill fairway environments using the TrackMan portable launch monitor.

Methods:

We used TrackMan to compare golf club movement adaptations in 42 PGs and 25 AGs. A 330-m driving range facing both the uphill (+5°) and downhill (-5°) fairways were used. The tee shot area was the only flat ground surface, with the uneven ground between the shot area and the 200-yard fairway.

Results:

The clubhead speed and attack angle were significantly higher among PGs than among AGs. PGs could adapt their swings to the uphill fairway by increasing the attack angle (3.6°±2.4) by 3.3° compared with the downhill fairway. The attack angle did not correlate with the launch angle among the AGs in the downhill condition, suggesting that they were unable to control the height of the ball based on the far side of the fairway.

Conclusion:

PGs increased the attack angle in uphill conditions, and their awareness of the affordance, which was different from that of AGs, allowed them to change the optimal ball trajectory to avoid perceived fairway risks. Thus, the more skill a player had, the better he was at recognizing the affordance of the visual field. PGs demonstrated a better ability to adapt to environmental constraints.

Keywords: Affordance, Ball trajectory, Club head movement, Golf, Motor skills, Visual fields.

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1. INTRODUCTION

The golf swing is a repetitive exercise, but many golfers face some problems in that their techniques cannot always be applied in a round because the conditions for every shot are different. Unlike other sports with conditions specified in terms of court size, they must play in huge golf courses with varied terrains under various constrained environments (field of view, slope, and weather conditions). In a recent study, a total of 953 shots of 22 PGs were analyzed in 16 different courses [1]. The results showed that the average slope of all shots was 4.6°, and

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approximately 80% of the shots had a slope of 1°–10°. Almost all players practice at flat golf driving ranges, although the player rarely ever has to hit a shot on flat ground in a golf match. Amateur golfers (AGs) often practice in golf ranges with a fixed environment to warm up and practice their skills before the round. However, in an actual course, all shots must be executed under constrained conditions, and AGs often take shots without being able to process the interference of the environmental information, leading to poor results [2, 3]. Although unexpected situations arise during every shot in a round, a professional golfer (PG) will attempt to perform appropriate shots while successfully overcoming these various disturbances.

Golf swings involve focusing on a stationary ball in a static address position and performing a fast, dynamic motion, and almost all measurements have traditionally been performed using high-speed cameras or ultrasonic Doppler for golf equipment in small indoor flat environments [4 - 6]. However, recent studies have compared shots in uphill and downhill conditions using sloping mats in indoor environments [7, 8]. These studies targeted low-handicap players (3-5) and 12 average golfers (10-15) using a 6-iron golf club on a 5° slope mat. In an attempt to resemble the outdoor environment during the second shot in golf, they used a virtual reality (VR) golf simulator (consisting of a screen placed in front of the golfer's position), and motion analysis was conducted under uphill and downhill conditions to measure the trajectory and center of gravity sway (taking the slope mat). The results showed that the distance traveled by the ball was significantly longer in the low-handicap group and that the leftward deviation from the target was considerably smaller [8]. Both studies found that the left-right deviation with respect to the target was the largest in uphill conditions, and the ball position with respect to the stance width (distance between the left and right feet) was closer to the center in downhill conditions. However, in these studies, the subjects could only recognize the slope by feeling the inclination through the soles of their feet. In addition, the VR screen was set to show the direction of flight and display the trajectory of the shot on flat ground. Therefore, these analyses did not include shots on slopes, which may interfere with the field of view and are characteristics of actual golf courses.

Recent trajectory analyses have shown that hitting the clubhead at 90° to the target contributes to most of the directionality and makes the golf ball fly straight in a horizontal direction [9 - 12]. From a kinematic point of view (Fitts' law) [13], AGs with swing speeds slower than PGs could easily repeat the square conditions of the swing. However, a study has clarified that PGs have a smaller standard deviation (variation) in a square face angle and better reproducibility [11]. In other words, PGs have fast club head speeds (CHSs) and are able to achieve the seemingly contradictory motor skill of swinging the club head at a square angle. Further, as low-handicap players make the ball "fly without curving," a remarkable difference could occur between PGs and AGs starting from the first shot. When humans perform the physical exercise for a certain purpose, they initially use visual details from the outside environment. Subsequently, depending on the perceived details, they consciously or unconsciously choose and express the optimal possible movements based on their physical function and past experiences. Gibson proposed the concept of affordance, which refers to how an individual adapts and acts on his or her internal environment in response to the information provided by the external environment [14]. While AGs tend to have an inconsistent play owing to the illusion that occurs in the retina during each shot, it is unclear whether PGs with skilled swing movements adapt to the perceptual information from the environment and then perform the same swing motion in all conditions. Therefore, confirming the difference in affordance between high- and low-skill shot movements based on the details provided by the environment is critical to understanding the basis of golf skills. In the present study, we hypothesized that PGs would perform the same stable club head movement if they shot toward uphill or downhill fairways, but AGs would have changes in the movement along with the forward fairway's landscape. This study aimed to analyze the club head movement at ball impact of a tee shot by PGs and AGs in swinging to uphill and downhill fairway environments at an outdoor golf course using the TrackMan portable launch monitor.

2. METHODS

2.1. Participants

A total of 25 AGs and 42 PGs who were A-grade members of the Professional Golfers Association of Japan were included in the study. AGs were right-handed players with an average age of 55.4 ± 11.9 years, a height of 172.5 ± 5.1 cm, and a weight of 73.8 ± 10.8 kg, with the best lifetime score being 85.4 ± 10.8 strokes. PGs were right-handed players with an average age of 38.1 ± 7.9 years, a height of 173.4 ± 5.0 cm, and a weight of 70.7 ± 7.6 kg. The study was approved by the Tokyo International University Academic Research Ethics Review (approval number: 2018-15). Information sheets containing a summary of the study were distributed to the participants, who received an additional oral explanation regarding the procedure. Participants provided written informed consent before involvement in any study-related procedures, all of which were executed according to the tenets of the Declaration of Helsinki. The subjects were informed that they had the freedom to withdraw from the study at any time, even after agreeing to participate, and that their routine medical care would not be affected by their decision to participate or not.

2.2. Experimental Setup

The study was conducted at Maoi Golf Resort Driving Range (Hokkaido, Japan). The driving range length was over 330 m between the tees to eliminate the risk of a drive reaching the opposite tee. Furthermore, there was a height difference of 30 m between the groups (Fig. **1**). The tests were conducted facing both the uphill and downhill slopes (+5° *vs*. -5°). The tee shot area was the only flat ground surface, and the ground between the shot area and the target of the fairway was uneven. Each subject used her or his own driver and the Royal and Ancient-conforming golf balls. A total of three uphill and three downhill shots (six shots) were used, and the mean data for each condition were used for further analysis.

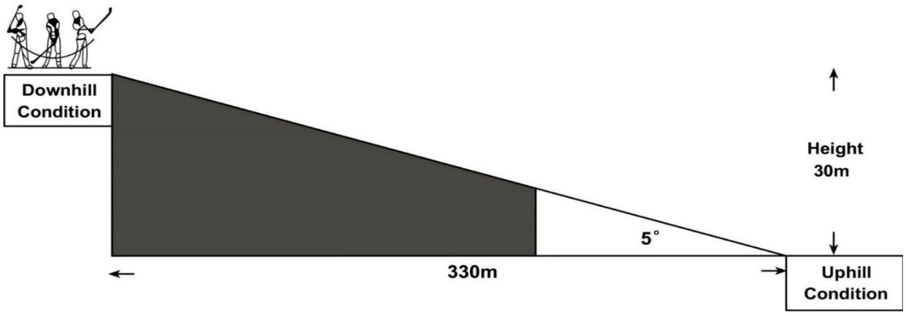

Fig. (1). Experimental setup for this study (inclination of the tee shot area was less than ±1.0°).

Since the CHS of the subjects was different, it was necessary to make the targets uniform. The midpoint of the 330 m-long driving range is 165 m, which is approximately 200 yards (181.5 yards to be exact); therefore, to meet the conditions as much as possible, both uphill and downhill, we established a direction target at the midpoint, the 200-yard point (Fig. **2**). The participants were only instructed to hit the ball toward a display yardage board at 200 yards from both sides of the tee. They were also instructed to perform their natural swing. No other instructions were provided. Before the actual test, the participants were allowed to practice a maximum of three shots as their warm-up. To avoid polarization, half of the participants began with three uphill shots followed by three downhill shots, and the other half began with three downhill shots followed by three uphill shots (Fig. **3**). After the first three shots, the participants were transported by a cart to the opposite end, taking the final three shots. The maximum testing time was 30 min, and the participants could visually check the ball trajectory but were not given any measurement feedback. Participants used the same ball and club, and the inclination of the tee shot area was less than ±1.0°.

Measurement of golf swing data was performed using TrackMan (TrackMan A/S, DEN) with information on clubhead movement and ball direction as criteria [9]. TrackMan uses radar beams as a microwave signal that reflects off-moving objects, such as golf clubs and balls. The reliability of Doppler launch monitors has been proven by comparison with high-speed camera data [15]. The horizontal angle and movement of the club head were analyzed using the face and path angles at the ball impact. In contrast, the vertical angle and movement of the club head were analyzed based on the attack angle and dynamic loft associated with the vertical launch angle [10]. The determination of the driver's club loft angle (static real loft) is quite difficult because this angle is affected by the setup position and type of measurement equipment. Therefore, TrackMan uses the dynamic loft angle, which involves the impact loft plus the human swing effect. The CHS was also measured because this parameter mainly affects the effectiveness of the ball impact [16].

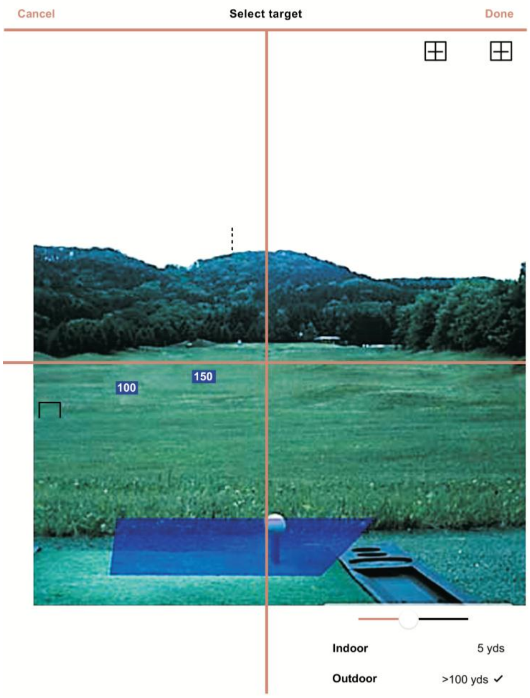

Fig. (2). View of the TrackMan setup against the uphill fairway to the 200-yardage board.

Fig. (3). Affordance of the environment in swinging to the downhill fairway.

2.3. Statistical Analysis

Measurement data were reported using mean and standard deviation in the two different slope conditions (uphill and downhill). Before performing further analysis, the CHS data were tested for normality using the Kolmogorov-Smirnov test against the CHS at uphill and downhill conditions in AG and PG. If the significance level is > 0.05, normality is not satisfied [17]. Each datum was entered into a 2 (Level: AG, PG) × 2 (Condition: uphill, downhill) mixed-design analysis of variance (ANOVA) for all independent variables (Table **1**). Post-hoc tests were performed using multiple repeated measures t-tests with Bonferroni correction. ANOVA data were assessed for normality and sphericity using Mauchly's test. A partial eta-squared (η_p^2) was used to calculate the effect size (0.01 as small, 0.06 as moderate, and >0.14 as large) [18]. Pearson correlation coefficients (r) were used to calculate the effect size (0.10, small; 0.30, moderate; and > 0.50, large) [19]. Finally, for clubhead angles of the five kinematic measurements, a linear partial correlation was used to analyze the relationship between uphill and downhill conditions in AGs and PGs. All significance levels were set to 0.05, and statistical analysis was performed using SPSS version 26.0 software (SPSS, IBM, JPN).

Table 1. Variables and statistics in swinging to uphill and downhill fairway conditions between AGs and PGs.

-	-	AG				PG				Main factor		Interaction
	-	Up	(SD)	Down	(SD)	Up	(SD)	Down	(SD)	Level	Condition	-
CHS	(m/s)	39.8	2.8	39.7	3.0	45.0	2.0	44.5	2.0	.000	.001	.054
Face	(deg)	-1.5	4.2	-2.4	3.7	-1.8	2.6	-3.1	2.4	.509	.003	.514
Path	(deg)	-2.9	5.9	-2.6	5.5	-0.4	2.5	-1.1	2.9	.044	.436	.150
Attack	(deg)	0.6	3.4	-0.7	3.1	3.6	2.4	0.3	2.7	.004	.000	.000
Dynamic	(deg)	16.2	2.7	14.6	3.2	16.0	1.9	13.2	2.5	.167	.000	.070
Launch	(deg)	13.7	2.4	12.3	3.0	14.2	1.9	11.4	2.6	.769	.000	.041

Note. AG, amateur golfer (n=25); PG, professional golfer (n = 42); deg, degrees; CHS, club head speed.

Table 2. Correlations between attack and launch angles (according to TrackMan).

-	Uphill		Downhill	
-	AG	PG	AG	PG
Correlation coefficient (r)	0.430	0.398	0.367	0.583
Significance level (p)	0.032*	0.009**	0.071	0.000**

Note. AG, amateur golfer (n=25); PG, professional golfer (n = 42); * *p*<0.05, ** *p*<0.01.

3. RESULT

Table **1** shows the data of shots on the downhill and uphill slopes obtained from TrackMan. CHS at uphill and downhill conditions in AGs were 39.8 ± 2.8 and 39.7 ± 3.0, respectively. The significance level of normality was 0.008 and 0.001, respectively. Therefore, the CHS in the AG was not satisfied in terms of normality. The CHSs at uphill and downhill conditions in PGs were 45.0 ± 2.0 and 44.5 ± 2.0, respectively. The significance level of normality was 0.200 and 0.200, respectively. Therefore, the CHS in the PG was satisfied in terms of normality. The ANOVA for the attack angle and the first-order interaction (two-way interaction) showed a significant difference between Level × Condition (F (1, 65) = 16.439, p = 0.000, η_p^2 = 0.580). The main effect of Level was significant (F (1,65) = 8.723, p = 0.004, η_p^2 = 0.118). In addition, the main effect of Condition was significant (F (1,65) = 89.616, p = 0.000, η_p^2 = 0.580). Therefore, the attack angle in the uphill condition was significantly larger than that in the downhill condition in both groups, and the PG values were higher than the AG values in both slope conditions. ANOVA for the launch angle and the first-order interaction (two-way interaction) revealed a significant difference between Level × Condition (F (1, 65) = 4.342, p = 0.041, η_p^2 = 0.063). The Level condition had no main effect. However, the main effect of Condition was significant (F (1,65) = 40.295, p = 0.000, η_p^2 = 0.383). Therefore, these results revealed that both groups showed significantly larger values in the uphill slope condition.

A follow-up of the two-way interaction showed no significant differences in CHS, face angle, club path, and dynamic loft. However, the main effects of Level and Condition on CHS were significant. Hence, the CHS of PGs was significantly higher than that of AG. Furthermore, the CHS in the uphill condition was higher than that in the downhill condition in both groups. The main effect of condition on the face angle was significant. Hence, the face angle in the uphill condition was significantly larger than that in the downhill condition in both groups. The main effect of Level on the club path angle was significant. The club path angle of PGs was significantly larger than that of AG, indicating that the club path direction of PGs approached the horizontal movement to the target line in both slope conditions. The main effect of the condition on dynamic loft was also significant, demonstrating a significantly larger dynamic loft angle in the uphill condition in both groups. Table **2** shows the Pearson correlation coefficients between the attack and launch angles of the AGs and PGs. PGs had a significant correlation in both slope conditions (p < 0.05), but AGs did not show a significant correlation in the downhill condition (r = 0.366, p = 0.071).

4. DISCUSSION

This study examined the adaptation of motor skills to the golf course environment by comparing the differences in the golf swings between PGs and AGs in uphill and downhill conditions, which affect the players' field of view. We also analyzed the clubhead behavior at ball impact of a tee shot by 42 PGs and 25 AGs in swinging to the uphill (+5°) and downhill (-5°) fairways toward a display yardage board at 200 yards using the TrackMan portable launch monitor. Our hypothesis was rejected, as we found that PGs always change the club head movement along the fairway-of-view condition.

Highly skilled PGs in this experiment achieved optimal ball trajectory by recognizing the affordance differently from AGs, as illustrated by the fact that the attack angle was increased by approximately 3.3° for a height difference of 30 m. The difference in the attack angle between the uphill and downhill conditions among the AGs was only 1° or less, whereas the PG had a difference of at least 3°, suggesting that PGs unconsciously changed their swing in response to the visual information. In other words, a highly-skilled PG uses details from the environment as cues to reduce the attack angle and hit the ball low in downhill conditions or to increase the attack angle and hit the ball high in uphill conditions. Hence, PGs chose to hit low balls in downhill conditions and high balls in uphill conditions. The attack angle is an indicator of the upward (+) or downward (-) motion of the club head with respect to the ground at impact and is a major factor in determining the height of a shot in the trajectory analysis [20]. The proper angle range for the driver is proposed to be -3° to 5° [9]. The launch angle is the index of the vertical trajectory angle of the ball, which is the sum of the attack angle and dynamic loft angle. In the AG, no correlation between the attack and launch angles was observed in the downhill condition, implying that they could not control the height of the ball according to the slope.

Uphill shots will land on the ground immediately after launch if the launch angle of the ball is low, making it impossible to maximize the flight distance. Therefore, we surmise that, based on a long experience, PGs unknowingly increased the launch angle to avoid mistakes and maximize the flight distance. In contrast, if the launch angle of the ball is high in downhill conditions, the flight time in the air becomes longer and the ball follows a more curved trajectory than that in the uphill condition before reaching the ground. In addition, the trajectory of the ball in downhill conditions is more affected by the wind owing to the longer flight time. Therefore, shots with a high launch angle may increase the risk of failure in a round of golf. We speculate that this is the reason why the PG decreased the launch angle in downhill conditions. There appeared to be a major difference between AGs and PGs in the perception of the information received from the environment, even under the same conditions.

A study in the field of perceptual psychology has revealed that the height (vertical position) of an object in the field of vision is a clue (information source) to the depth (relative distance) and that there is a horizon-ratio relation between the relative height from the horizon and the actual horizontal distance [21]. The golf course has various fields of view. In particular, when the tee shot is downhill, the far side hill is not a limiting factor for the player's view; the relative height from the horizon to the ball landing point can be precisely confirmed in this condition, and thus, the player can execute their affordance (Fig. **3**). However, in the uphill condition, it is difficult to receive an attribution of height; thus, players have to deal with the loss of the target.

Interestingly, there was a large difference in the affordance behavior of skilled PGs in driver shots that require a high degree of skill because of differences in the visual environment. This ability is thought to be acquired during the autonomous movement stage by repeated swing practice. PGs have a vast experience playing in various golf courses, which have automated golf swings. In the process of becoming skilled in golf swings, it is believed that swings suitable for the environment gradually and unconsciously become established by repeating failures while aiming for the optimal swing for the environment. The results suggest that new affordances are induced according to the golf course's environment, forming an interrelationship between affordances and behaviors [2].

In recent years, the method of motor learning in which discovery learning is promoted by using various constraints for sports skill acquisition is referred to as a constraint-led approach (CLA) [22, 23]. One important point when using the CLA is that coaches coordinate environmental and task constraints with the learner's current abilities and skill level to facilitate adaptation to practice and learning opportunities [24]. If the difference between the uphill and downhill conditions adopted in this experiment is seen as a limiting factor, there is a potential to contribute to improving the performance of golfers, including AG. In particular, past problems in coaching golf have been the excessive pursuit of a perfect swing and of techniques performed on a flat, featureless golf course [2].

CLA has been developed in the field of physical education pedagogy for children to deepen the enjoyment of exercise tasks. In recent years, the range of applications has expanded to the field of motion perception in tennis and golf [2, 25 - 27]. In other ball sports, experts adopt modes of movement that are different from normal movements because of restrictions in the environment they perceive. A study on basketball free throws reported that reducing the diameter of the basketball rim by 0.10 m results in an increase in the ball release angle [28]. In this experiment, the diameter was made smaller than the standard rim by 0.10 m, and basketball players with advanced shooting skills increased their shooting success rate by increasing the approach angle of the ball when it goes through the rim. This investigation suggested that if the main problem in players with low free-throw success rates was a smaller ball release angle, the shooting success rate could be increased by increasing the release angle. This can be achieved by practicing a rim with a small diameter.

Furthermore, a previous study investigated the swing trajectory of equipment in baseball players [29]. With a wall projecting a VR baseball stadium, subjects in the constraint group were instructed to hit the ball over the wall, and their results were compared with those of an internal focus group who were instructed to move their arms at an upward angle. The results confirmed that the launch angle and number of home runs increased in the constraint group. Similar results were observed in an external focus group that was instructed to aim and hit the ball on the bottom half. The results of these experiments suggest that affordances may be recognized and that optimal movements may be derived even under restricted conditions among skilled participants. If behaviors and movements change depending on the awareness of the player based on the information received by peripheral vision, further advances in VR might be useful for improving complex motor learning, such as golf swing in indoor environments. However, enhancing affordances by training with all senses in a constrained outdoor environment is crucial. Moreover, the interpretation of excessive feedback of data from trajectory analysis equipment might adversely affect an individual's ability to perform [18]. Thus, coaches must take great care when using results correctly in an appropriate learning environment so that players can achieve the desired goals.

4.1. Limitations

In this study, we carried out the experiments by looking for an outdoor driving range with an infinitely flat surface (±1°), uphill and downhill slopes of +5° and -5°, respectively, in the hitting direction, and sufficient driving range length to hit both towards uphill and downhill. Despite taking measurements under normal flat ground conditions, it was not performed because it was necessary to move to a completely different place, and the burden on the subject was considered. Furthermore, it has become a common practice in recent years for PGs to use a portable launch monitor to acquire shot data taken at each hole; thus, in the future, we would like to investigate the influence of perceptual information from the environment in a competition golf course among golfers with different skill levels.

CONCLUSION

The results of this experiment confirmed that the higher the player's skill level, the better their recognition of the affordance of the visual field and the greater their ability to adapt to environmental constraints. Conversely, as low-skilled players were inferior in terms of affordance recognition (information assembling ability), future golf research should advance with practical interventions with constraint conditions.

PRACTICAL APPLICATION

The results of this study showed that golfers are severely constrained by the visual environment when swinging to uphill fairway conditions and need to change their position at the address by ignoring the details of the forward view. If the swing pattern in a normal flat condition is in an upward launch angle, it is recommended to use the second floor of the golf driving range and coordinate the swing movement by resembling the downhill visual field. Conversely, golfers with excessive downward attack angles and low launch angles in flat ground conditions should practice their swings resembling an uphill visual field on the first floor. However, it is necessary to avoid excessive swing changes that could result in missed shots.

LIST OF ABBREVIATIONS

PG	=	Professional Golfer
AG	=	Amateur Golfer
CHS	=	Club Head Speed
VR	=	Virtual Reality
ANOVA	=	Analysis of Variance

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Tokyo International University Academic Research Ethics Review (approval number: 2018-15).

HUMAN AND ANIMAL RIGHTS

No animals were used in this research. All human research procedures were followed in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

CONSENT FOR PUBLICATION

All participants received verbal and written explanations about the protocol before participating in the study.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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