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Development and reliability of a visual-cognitive medial side hop for return to sport testing

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Abstract

Objectives: To develop and evaluate the reliability of a new visual-cognitive medial side hop (VCMH) test that challenges physical and cognitive performance to potentially improve return to sport testing.

Design: Test-retest experimental design.

Setting: Laboratory.

Participants: Twenty-two healthy college students participated (11 females; 23.5 ± 3.64 years; 172.9 ± 11.58 cm; 74.1 ± 17.25 kg; Tegner Score 5.6 ± 1.1).

Main outcome measures: Subjects performed a medial side hop for distance with and without a visual-cognitive task (VCMH). Maximum hop distance and cognitive errors were measured.

Results: There was strong reliability for the traditional medial side hop ($ICC_{3,1}$ = 0.88[0.72, 0.95]; SEM = 7.16 cm) and VCMH distances ($ICC_{3,1}$ = 0.86[0.66, 0.94]; SEM = 6.82 cm). Maximum hop distance was significantly lower during the VCMH (86.9 ± 18.2 cm) compared to

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Declaration of competing interest
This manuscript represents original unpublished material and is not under consideration for publication elsewhere. This manuscript is the original work of the authors and all the authors have approved its submission. There is no potential conflict of interest. Specifically, there are no financial relationships with any manufacturers, including, but not limited to grants, honoraria, consulting fees, royalty fees, ownership, or support in preparation of the manuscript.

Ethical Statement
The Ethical Guidelines have been followed and approved by the Ohio University Biomedical IRB Committee, approval number 18-X-233. All individuals were 18 years or older and provided their informed consent. They were allowed to ask questions and drop from the study at any point.

Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2022.07.004.

the traditional medial side hop (96.3 ± 20.7 cm; $p < 0.05$; $d = 0.74$), with a performance deficit of 9.69%.

Conclusion: The VCMH has high test-retest reliability and resulted in a significant dual-task cost with a reduction in physical performance when compared to the traditional medial side hop.

Keywords

Functional performance; Working memory; Rapid visual encoding; Lower extremity

1. Introduction

In strategy sports, athletes are required to visually process multiple stimuli (i.e., opponents, balls) while simultaneously performing high intensity multi-directional movements. For example, soccer players engage visual-cognitive processes to integrate sensory information from the environment to track the ball, opponents, teammates, and plan goal directed actions (Burris et al., 2019; Mann et al., 2007; Williams et al., 1994). Elite athletes are better able to process and dissociate necessary environmental information such as rapid object tracking and gaze fixation while maintaining motor coordination relative to sub-elite counterparts (Burris et al., 2019; Vickers & Adolphe, 1997; Williams et al., 1994). Recently, the implications of visual-cognitive ability have extended beyond athletic performance and has been found to influence prospective anterior cruciate ligament (ACL) injury risk and associated neuromuscular control (Herman and Barth, 2016; Monfort et al., 2019; Swanik et al., 2007). Visual-cognition also plays a role in potential proprioception and dynamic stability compensations via altered neural activity after ACL injury (Chaput et al., 2022). Although current literature demonstrates visual-cognitive function as an important risk factor influencing injury risky biomechanics in healthy athletes, and as a potential compensation to maintain physical performance after ACL reconstruction, few return to sport (RTS) assessments employ a simultaneous standardized visual-cognitive challenge with physical movement assessment to evaluate readiness to RTS.

Traditional RTS assessments for lower extremity injuries primarily measure physical performance, such as isolated muscle strength or select functional movements like hopping or landing from a jump. The Noyes' hop tests (single hop, triple hop, crossover hop, and 6-m timed hop) are a widely used functional RTS metric following ACL injury and other lower extremity injuries. Hop tests aim to determine physical readiness to RTS, however demonstrate limited sport utility by isolating only unilateral physical performance without consideration for visual-cognitive challenges inherent in sport. To fill this gap, Millikan et al., (Millikan et al., 2018) developed four highly reliable neurocognitive single leg hop tests that augmented the four Noyes' hop tests challenging reaction time, working memory, visual scanning, response inhibition, and visual processing. In healthy participants, incorporating visual-cognitive stimuli decreased hopping performance as compared to traditional hop tests (Millikan et al., 2018; Simon et al., 2020). However, the neurocognitive hop tests developed by Millikan et al. (Millikan et al., 2018) primarily biased forward linear functional performance and overlooked key lateral or rotational movement coordination deficits. Recently, medial and rotational hop tests have demonstrated excellent reliability and may be more likely to reveal greater asymmetries between legs in ACL-reconstructed individuals when compared to the traditional forward hop tests (Dingenen et al., 2019). Medial and rotational hops have been hypothesized to elicit greater knee valgus, hip adduction, and medial rotation upon landing (all risk factors for a lower extremity injury) compared to traditional hops (Dingenen et al., 2019). However, these tests only tax the physical system and integrating visual-cognitive processing could potentially be more sensitive to detect performance insufficiencies, which could enhance traditional RTS screening.

Therefore, the purpose of this study was to develop and evaluate the reliability of a new visual-cognitive medial side hop (VCMH) test that challenges both physical and visual-cognitive performance. The VCMH test incorporates frontal plane stability while simultaneously performing a continuous visually dominant dual-task perturbating visual-spatial working memory and rapid visual encoding.

2. Methods

2.1. Participants

Twenty-two healthy college students (11 females, 11 males; 23.5 ± 3.64 years; 172.9 ± 11.58 cm; 74.1 ± 17.25 kg; Tegner Score 5.6 ± 1.1) volunteered to participate. The sample size was based on a power analysis for the established reliability of the medial side hop for distance (Dingenen et al., 2019) and for adding a visual-cognitive component to different hop tasks (Millikan et al., 2018). Dingenen et al. (Dingenen et al., 2019) found the medial side hop for distance had an intraclass correlation coefficient (ICC) of 0.97e0.98 for dominant and non-dominant legs with 95% confidence intervals (CI) ranging from 0.90 to 0.99; thus, a sample size of 6 subjects with 2 observations per subject achieves 87% power to detect an ICC of 0.9 under the alternative hypothesis when the ICC under the null hypothesis is 0.2 using an F-test with a significance level of 0.05. Additionally, Millikan et al. (Millikan et al., 2018) found the augmented Noyes' hop tasks with added visual-cognition had ICCs ranging from 0.87 to 0.98 with 95% CIs ranging from 0.70 to 0.99 across all tasks and dominant and non-dominant limbs. Thus, a sample size of 16 subjects is needed with 2 observations per subject to achieve 82% power to detect an ICC of 0.7 under the alternative hypothesis when the ICC under the null hypothesis is 0.2 using an F-test with a significance level of 0.05. However, a convenience sample of 22 was recruited as this is a similar sample size in previous reliability studies. Exclusion criteria included history of lower extremity surgery, any injury within the past 6 weeks, ligament damage to the knee or any lower extremity injury that impaired physical activity, and medical history of nervous system dysfunction/impairment. This study was approved by the Institutional Review Board (IRB) at Ohio University and participants signed an informed consent form, along with medical history and activity level questionnaires prior to participation. Leg dominance was defined as the participant's preferred leg to kick a ball, and was used for all hopping assessments (Melick et al., 2017).

2.2. Procedures

Two identical testing visits separated by twelve to seventeen days (14 ± 1.04 days) to limit carryover or learning effects were completed. On both visits, participants performed the visual-cognitive task (Space Task) in isolation, a medial side hop for distance, and a medial side hop for distance with simultaneous visual-cognitive task. The order of tasks for both days was completed in a fixed order with the visual-cognitive task in isolation completed first, followed by the medial side hop for distance, and lastly the medial side hop for distance with simultaneous visual-cognitive task was completed. For the baseline visual-cognitive task, participants completed one practice trial followed by two trials of the Space Task. Participants then completed a traditional medial side hop for distance and the visual-cognitive medial side hop (VCMH). Two practice trials and three successful trials were completed for all hopping tasks. Participants were instructed to "hop as far as you can, then hold the stance for 30s". All testing was completed by the same examiners.

2.2.1. Baseline visual-cognitive (space) task—A modified Space Task challenging rapid visual encoding and spatial memory was used as the visual-cognitive task (Appelbaum et al., 2012, p.11; Lu et al., 2005; Unsworth et al., 2014). Participants stood 2m away from an 80-inch television screen (Sharp Electronics Corporation, Montvale, NJ) in a comfortable, relaxed position. Using Microsoft PowerPoint, a circular array of eight letters were displayed around a central dot on the screen for a brief period of time (100 ms) (Fig. 1 A–D). The 8 black uppercase letters were chosen randomly from a set (D, F, J, K), with the constraint that adjacent letters could not be the same. Once the letters disappeared, a red line would appear as an indicator for 1.9s for the participant to verbally recite the letter at the corresponding location for delayed recall. Participants were instructed to focus their attention on the center fixation dot during the entire trial. During the 30s trial, circle letter arrays and indicator lines were presented ten times. One 10s practice trial followed by two 30s test trials were completed on both days. Baseline visual-cognitive performance was assessed by counting cognitive errors (incorrect verbal response) and the least number of errors was used for analyses.

Fig. 1A–D. Slide A was presented on the screen first for 400ms and was followed by slide B for 100ms in which the participant had to keep eyes focused on the center fixation dot. Slide C was then presented for 640ms, followed by slide D for 1.9s in which the participant had to recall the previous letter displayed where the red line points.

2.2.2. Traditional medial side hop—Each participant stood on their dominant leg; hands placed on their hips with the medial border of their foot aligned with the end of a tape measure. Participants were instructed to "hop medially as far as you can and then hold the landing for 30s. You can hop whenever you are ready". The tape measure was placed anterior to the participant and although not cued, participants consecutively landed along the tape measure. There was no focus of attention provided in the task as done in previous literature (Ebert et al., 2021; Ebert et al., 2021). One practice trial and three successful trials were completed. A successful trial was defined as sticking the landing and maintaining balance for 30s without foot shift, putting the opposite foot down, or removing their hands from their hips. A physical miss was counted and the trial was repeated if the participant violated these parameters. The maximum hop distance was used for analysis.

2.2.3. Visual-cognitive medial side hop (VCMH)—The VCMH was executed by simultaneously performing the modified Space Task and medial side hop for distance as described above. Each participant was asked to initiate a medial side hop when the first circular array of letters from the Space Task appeared on the TV screen. The Space Task was performed for 30s while simultaneously maintaining single-limb balance upon landing from the medial side hop. Participants performed two 10s practice trials for task familiarization. The first practice trial was a cognitive only practice where the Space Task was displayed, and participants verbally indicated when the medial side hop would be performed. The second practice trial was a 10s version of the VCMH. Three successful VCMH trials were completed. A successful trial was defined as the participant sticking the landing and maintaining balance for 30s without the contralateral foot touching down or removing their hands from their hips. A physical miss was counted and the trial was repeated if the participant did not maintain balance or hopped at an incorrect timing with the Space Task slides.

2.3. Statistical analyses

Test-retest reliability was assessed by calculating Intraclass Correlation Coefficients (ICC) using a two-way mixed effects model with absolute agreement with 95% confidence intervals. Standard error of the measurement (SEM) and 95% minimal detectable change (MDC) for physical performance and cognitive misses were calculated. Bland-Altman plots were constructed to evaluate any systematic differences between test days. Additionally, a paired samples t-test was used to determine if there were differences in hop distance, cognitive misses, and physical errors between testing conditions (traditional vs. VCMH) for the first day of data collection with alpha set at 0.05. For each visit, the maximum hop distance (cm) for both the traditional and VCMH was used for analyses, and the least number of cognitive misses (wrong answers) were used for analyses for the baseline and VCMH conditions.

3. Results

Table 1 contains the descriptive statistics for each task for both days of testing. The ICC, SEM, and MDC values for hop distance and cognitive misses across each task are represented in Table 2. The traditional medial side hop for distance and the VCMH demonstrated excellent reliability ($ICC_{3,1} = 0.88$; $ICC_{3,1} = 0.86$, respectively). Additionally, the cognitive misses demonstrated excellent reliability for the baseline and VCMH tasks ($ICC_{3,1} = 0.89$; $ICC_{3,1} = 0.85$, respectively). The Bland-Altman plots indicate no systematic differences for all tasks (Fig. 2 A–D). Maximum hop distance was significantly decreased during the VCMH compared to the traditional medial side hop (Table 3). The addition of the Space Task in the VCMH decreased hop distance by 9.69%. However, cognitive and physical misses did not significantly change between the baseline and VCMH tasks ($p > 0.05$).

4. Discussion

The purpose of this study to was to develop and evaluate the reliability of a new VCMH test. Strong reliability was demonstrated for hop distance and cognitive misses during both the traditional medial side hop and VCMH tests. The VCMH MDC is within prior MDCs of other functional tests (Dingenen et al., 2019; Kockum and Heijne, 2015) and the dual-task cost is far below injury induced hop deficits (Kivlan et al., 2013; Simon et al., 2021)

Additionally, maximum hop distance significantly decreased during the VCMH compared to the traditional medial side hop. These findings indicate that a simultaneous visual-cognitive task with the medial side hop for distance can incur a dual-task cost and could have viability as a functional test to detect overreliance on or compensation with visual-cognition for performance.

The VCMH test was designed to challenge rapid visual-cognitive processing and examine the effect on physical performance (hop distance) with the goal to improve the construct validity of RTS testing (Sousa et al., 2017; Wellsandt et al., 2017). Prior research has demonstrated that challenging visual-cognitive processing with physical performance through neurocognitive dual-tasks is reliable and may enhance RTS test batteries to challenge elements of neural processing that are not captured in traditional RTS testing (Chaput et al., 2022; Millikan et al., 2018; Ness et al., 2020; Criss et al., 2020). The VCMH dual-task cost may be partially explained by the capacity theory of attention, whereby the typical utilization of visual-spatial processing for managing hop execution and landing are additionally taxed with the Space Task. The capacity theory of attention indicates a limit on the ability to perform simultaneous or divided attention associated cognitive work (Kahneman, 1973; Price et al., 2009). The amount of attention required by a task determines how much capacity remains for the concurrent task (i.e. a secondary task with higher cognitive load results in poorer motor performance) (Laurin and Finez, 2020; Price et al., 2009). Competitive athletes are required to distribute attentional demands across multiple stimuli (other player positioning, ball tracking, coach commands, etc.) while maintaining their own online physical performance. Sport-related dual tasks that place simultaneous demands on visual-spatial attention and working memory along with functional performance require increased cognitive engagement, potentially resulting in either task degradation as attentional capacity is reached (Laurin and Finez, 2020; Vaughan & Laborde, 2021).

The significant reduction in hop distance (dual-task cost) with the added visual-cognitive task may indicate individuals prioritized the visual-cognitive task over the functional task (as there was no significant increase in cognitive errors from baseline to VCMH). This has been supported in previous research using different dual-tasks in the sagittal plane. Simon et al. (Simon et al., 2020) found similar reductions in hop distance with the addition of neurocognitive dual-tasks on traditional hop tests (e.g. single leg hop for distance, triple hop for distance, etc.) using the FitLight system. Integration of digit span recall tasks on tuck jump movement performance has also been shown to elicit diminished performance when compared to baseline tuck jump movement analyses (Schnittjer et al., 2021). Although these assessed different aspects of function and cognition compared to the VCMH, physical performance was similarly diminished in the cognitive dual-task conditions. A key difference between the VCMH and prior dual-task sports related functional tasks, is that the prior work primarily challenged sagittal plane movement or stability while the VCMH challenges frontal plane control.

The only prior study to our knowledge to add a dual-task condition to a frontal plane return to sport functional assessment modified the medial hop test by also adding a visuospatial (DOTS) task (Ness et al., 2020). However, there were no significant deficits in hop performance (no dual-task cost) by challenging the medial triple hop with a DOTS task requiring subjects to recall a randomized number of red dots amongst blue dots on a TV screen (Ness et al., 2020). The DOTS task (Ness et al., 2020) may not have been challenging enough as the dots were presented on the screen for a longer amount of time (1.5s) taxing visual memory and allowing for potential completing hops and memorization in sequence as opposed to our Space Task (100 ms) challenging rapid visual encoding. The VCMH test challenges both visual-cognitive processing with frontal plane stability and demonstrated high reliability indicating potential utility to better simulate the demands of sport while identifying physical performance deficits, making it a potential tool for future use in RTS testing.

4.1. Clinical implications

Previous research supports the use of a battery of assessments to determine RTS readiness after ACL reconstruction, including a thorough assessment of strength, power, fatigue, functional performance, psychological testing, and patient-reported outcomes (Davies et al., 2017; Noyes, Barber-Westin and Mangine, 1991; Wilk et al., 1994). The current standard of functional tests used for RTS clearance consist of horizontal or vertical hop tests and may lack challenging frontal plane stability. Additionally, many RTS tests do not consider cognitive contributions to motor control that mimic sport. Attending to multiple cognitive tasks is crucial in sport participation, therefore adding a secondary task to the RTS hopping tests may challenge aspects of visual-cognition that are employed in sport and improve sensitivity of RTS testing (Buckthorpe, 2019; Dingenen and Gokeler, 2017). The results of this study demonstrate that a visual-cognitive dual-task challenge during medial hopping revealed greater performance deficits than the traditional medial hop test, supporting potential RTS utility.

4.2. Limitations and future directions

The participants in this study were college aged recreational level athletes, therefore, generalizing to other populations may be limited. Task familiarization or learning may have occurred between the 2 day as the dual-task cost was reduced from day one to day two. These potential effects could be explored over the course of musculoskeletal rehabilitation in further research. Additionally, during testing shoes were not standardized and may influence hopping performance. The Space Task was designed to only challenge key components of visual working memory and rapid visual encoding, which are commonly utilized in sport performance (Furley and Memmert, 2010; Mann et al., 2007; Williams et al., 1999). However, successful sport participation relies on many other visual-cognitive processes that are difficult to integrate into a single clinical test. There is a need for additional visual-cognitive and physical performance outcome measures to better assess the specific phases of the VCMH task. Future research should aim to examine the performance during the VCMH test or other continuous visual-cognitive challenges in athletes who have a history of or are RTS following lower extremity injury. The development of multi-plane functional tests with continuous visual-cognitive challenges that more closely resemble the dissociation of cognitive processing and motor control necessary for high performance in chaotic sport environments is warranted.

5. Conclusion

Overall, the VCMH demonstrated high reliability and resulted in a significant reduction in maximum hop distance when compared to the traditional medial side hop for distance. This study provides evidence that a continuous rapid visual-cognitive challenge can be added to the medial side hop test and increases performance difficulty, potentially supporting utility of the VCMH as a novel tool for RTS assessment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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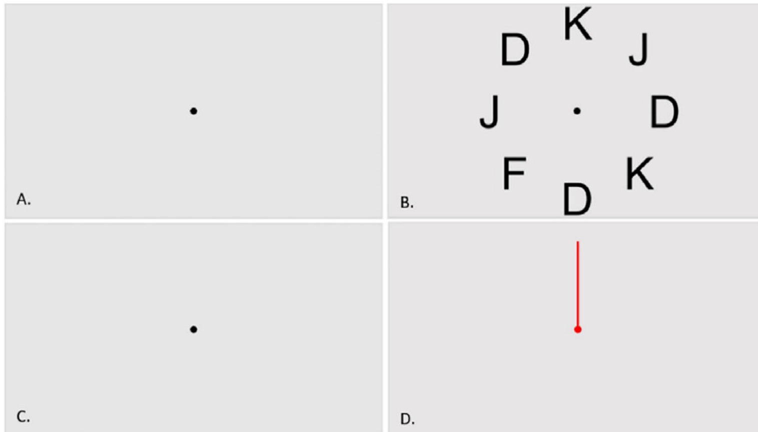

Fig. 1.
A–D. Space task PowerPoint slides.

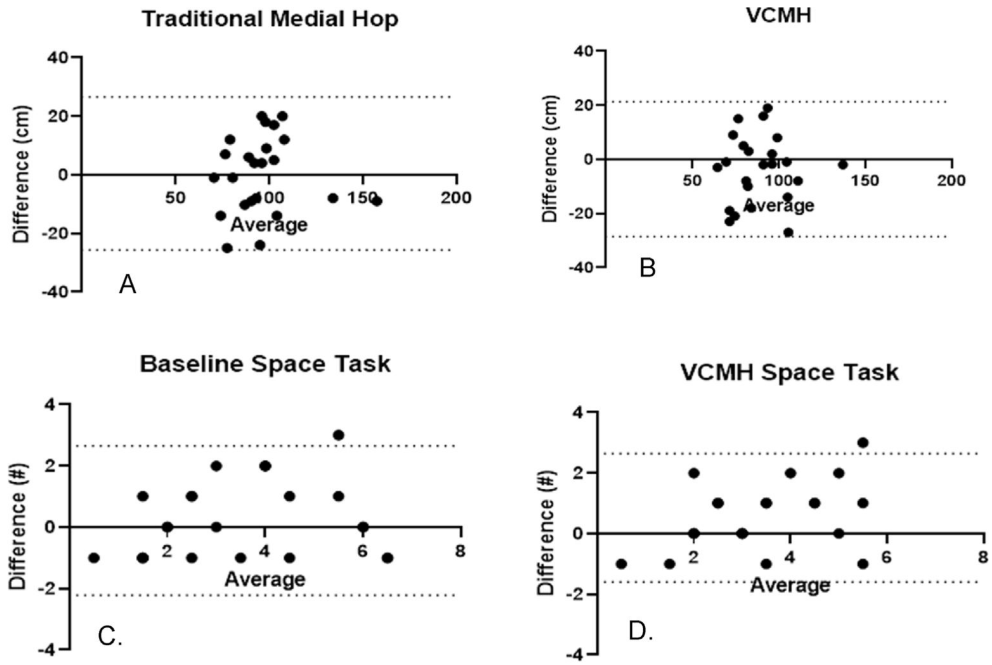

Fig. 2.

AD. Bland Altman plots for traditional medial hop, VCMH, and cognitive Errors
VCMH – visual-cognitive medial side hop.

Table 1

Descriptive statistics for day 1 and 2 traditional medial hop, VCMH, physical and cognitive errors.

	Day 1	Day 2	Mean Difference
Baseline Space Task Cognitive Miss (#)	3.6 ± 2.0	3.4 ± 1.8	−0.2 ± 0.4
Traditional Medial Side Hop (cm)	96.3 ± 20.7	95.8 ± 20.2	−0.5 ± 2.8
Traditional Hop Physical Miss (#)	1.9 ± 1.4	2.1 ± 1.2	0.2 ± 2.2
VCMH (cm)	86.9 ± 18.2	90.5 ± 17.8	3.6 ± 2.7
Dual Space Task Cognitive Miss (#)	3.6 ± 1.7	3.1 ± 1.3	−0.5 ± 0.4
VCMH Physical Miss (#)	2.0 ± 1.3	1.9 ± 1.0	−0.01 ± 1.6

VCMH – Visual-Cognitive Medial Side Hop.

Table 2

ICCs, SEM, and MDC for traditional medial hop, VCMH, and cognitive errors.

	ICC (95% Cl)	SEM	MDC
Baseline Space Task Cognitive Miss	0.89 (0.73, 0.95)	0.7	1.9
Traditional Medial Side Hop	0.88 (0.72, 0.95)	7.2	19.8
VCMH	0.86 (0.66, 0.94)	6.8	18.9
Dual Space Task Cognitive Miss	0.85 (0.65, 0.94)	0.7	1.9

ICC – Intraclass Correlation Coefficients; SEM – Standard Error of the Measurement; MDC – Minimal Detectable Change; VCMH – Visual-Cognitive Medial Side Hop.

Table 3

Descriptive statistics for the comparison of traditional task to VCMH task distance and errors.

	Traditional Medial Side Hop	Baseline Cognitive Task	VCMH Task	Effect Size	VCMH Cognitive Cost	Mean Difference
Maximum Distance (cm)	96.3 ± 20.7	N/A	86.9 ± 18.2	0.74	−9.69%	−9.3 ± 2.6[a]
Cognitive Misses (#)	N/A	3.6 ± 2.0	3.6 ± 1.7	0.00	0%	0.0 ± 0.48
Physical Misses (#)	1.9 ± 1.4	N/A	2.0 ± 1.9	0.06	N/A	0.13 ± 2.2

[a]Significant difference $p < 0.05$

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