Online October 8, 2021
Journal of Neuroendovascular Therapy 2022; 16: 294–300
DOI: 10.5797/jnet.oa.2021-0053

Original Article

The Influence of Experience on Gazing Patterns during Endovascular Treatment: Eye-Tracking Study

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Objective: In various fields, differences in eye-gazing patterns during tasks between experts and novices have been evaluated. The aim of this study was to investigate gazing patterns during neuro-endovascular treatment using an eye-tracking device and assess whether gazing patterns depend on the physician's experience or skill.

Methods: Seven physicians performed coil embolization for a cerebral aneurysm in a silicone vessel model under biplane X-ray fluoroscopy, and their gazing patterns were recorded using an eye-tracking device. The subjects were divided into three groups according to experience, highly experienced (Expert) group, intermediately experienced (Trainee) group, and less experienced (Novice) group. The duration of fixation on the anterior–posterior (AP) view screen, lateral (LR) view, and out-of-screen were compared between each group.

Results: During microcatheter navigation, the Expert and Trainee groups spent a long time on fixation to AP, while the Novice group split their attention between each location. In coil insertion, the Expert group gazed at both the AP and the LR views with more saccades between screens. In contrast, the Trainee group spent most of their time only on the AP view screen and the Novice group spent longer out-of-screen.

Conclusion: An eye-tracking device can detect different gazing patterns among physicians with several experiences and skill levels of neuroendovascular treatment. Learning the gazing patterns of experts using eye tracking may be a good educational tool for novices and trainees.

Keywords eye tracking, coil embolization, skill learning

Introduction

Where to gaze during tasks is important for both carrying out and safety of the procedure. A psychologist, William James, stated "Keep your eye at the place aimed at, and your hand will fetch (the target); think of your hand, and you will likely miss your aim."[1)] It can also be applied to the medical field. To perform procedures of surgery and catheterization, it is important to correctly gaze at the site where should be paid attention for safe treatment. Neuroendovascular treatment is performed using a biplane angiography device in many cases, referring to two screens, so that it is necessary to gaze at the correct screen at the correct time.

Physicians highly skilled in neuroendovascular treatment perform treatment with the knowledge of the sites required to be paid attention to, but beginners do not understand where to gaze in many cases. Therefore, education of where to look on the screen during the neuroendovascular procedure is important. However, since quantitative measurement of sites gazed at is not easy, it is difficult to learn objectively where highly skilled operators gazed at during treatment. Moreover, measurement of sites not seen is also difficult, so that it is difficult to point out what part beginners do not gazed at during the procedure.

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Received: March 29, 2021; Accepted: August 25, 2021
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Recently, several studies using eye trackers as a method objectively measuring gaze have been reported. An eye tracker is a device measuring gaze from information of pupil position movements. It is capable of objectively evaluating the site gazed at by superimposing an image of the subject's visual field recorded by a frontal camera with the pupil position.[2] Gaze measurement using eye tracking in radiograph interpretation[3–5] and surgical treatment[6,7] has recently been reported, but there have been fewer reports on neuroendovascular treatment. Moreover, differences in gaze during neuroendovascular treatment depending on the treatment experience and technical level have not been investigated. In this study, we investigated whether differences in gaze during neuroendovascular treatment corresponding to the experience of neuroendovascular treatment can be analyzed using an eye tracker.

Materials and Methods

The subjects were seven physicians engaged in neuroendovascular treatment at our hospital with different levels of experience in neuroendovascular treatment. They were divided into the following three groups: 1) Expert group: Physicians with 10 years or longer experience in neuroendovascular treatment qualified as a specialist or trainer certified by the Japanese Society for Neuroendovascular Therapy, 2) Trainee group: Physicians with three years or longer but shorter than 10 years of experience in neuroendovascular treatment, and 3) Novice group: Physicians with two years or shorter experience in neuroendovascular treatment. In each subject, eye movements were recorded using the eye tracker and the differences in their gaze during neuroendovascular treatment were investigated.

For operation of the treatment, a human vascular model for endovascular surgery training simulation, EVE (FAIN-Biomedical, Okayama, Japan), was used, and gaze while applying coil embolization for cerebral aneurysm under fluoroscopy was extracted using the eye tracker. The following two procedures were targeted: 1) Procedure 1: Microcatheter navigation: From the appearance of the microcatheter with an inserted micro guide wire on the fluoroscopy screen to the placement of the microcatheter in the aneurysm and 2) Procedure 2: Coil placement: From the entrance of one coil into the aneurysm to reaching the detachment point. For the aneurysm, an aneurysm simulating an internal carotid artery–anterior choroidal artery aneurysm present in EVE was used. The aneurysm diameter was 9 mm, and the neck size was 6 mm. All subjects performed the operation on the same aneurysm using an identical micro guide wire (Soft-tip Transend guidewire; Stryker, Kalamazoo, MI, USA), microcatheter (Excelsior SL-10 microcatheter; Stryker), and coil (Target Soft 8X30 mm; Stryker). For the X-ray fluoroscopy, a biplane angiography device was used; two images, the anterior–posterior (AP) and lateral (LR) views, were projected to a 19-inch monitor; and operation was performed with the projection of both images. The AP view was set to observe the positional relationship with the parent artery and aneurysm neck, and the LR view was prepared to be able to confirm the whole image of the aneurysm. The monitor projecting the fluoroscopy image was arranged at a frontal position 70–80 cm from the subject and operation was performed. To prevent bias, each operator initiated the operation while seeing it for the first time or nearly the first time. The operation was performed without knowing the gaze data of the other subjects.

Extraction of gaze using the eye tracker

For gaze measurement, a Pupil Core eye-tracking headset (Pupil Labs, Berlin, Germany) was used (**Fig. 1**). The eye tracker was equipped with three cameras. Two cameras were infrared cameras equipped inward in the bilateral lower regions of the glasses, and the directions of the bilateral eyeballs of the wearer were measured to analyze gaze. The remaining camera was a world camera equipped outward in the upper region of the glasses, and its acquired image was of the visual field of the wearer. On the software of the computer, gaze information was displayed in the visual field acquired by the world camera. The coordinates of gaze were output as coordinate data, and whether the same site was stared at for a prolonged time or multiple sites were alternately seen could be numerically analyzed.

The subjects performed both Procedures 1 and 2 while wearing the eye tracker, and eyeball movement data during the operation were recorded. The recorded gaze information was converted to coordinate data and superimposed with the visual field recorded by the world camera. The gaze of each subject during the operation was classified into three regions: AP view monitor, LR view monitor, and out-of-screen. Annotation for classification of gaze was performed visually by blinded specialized staff. The duration of gaze at each of the three regions and the number of movements among the regions were calculated. Since the operative time differed among the operators, the investigation items were set as follows: The ratio of time looking at each monitor and out-of-screen, duration of single gaze until transfer to the next gaze region, and the numbers of gaze movements at the AP and LR view monitors per minute.

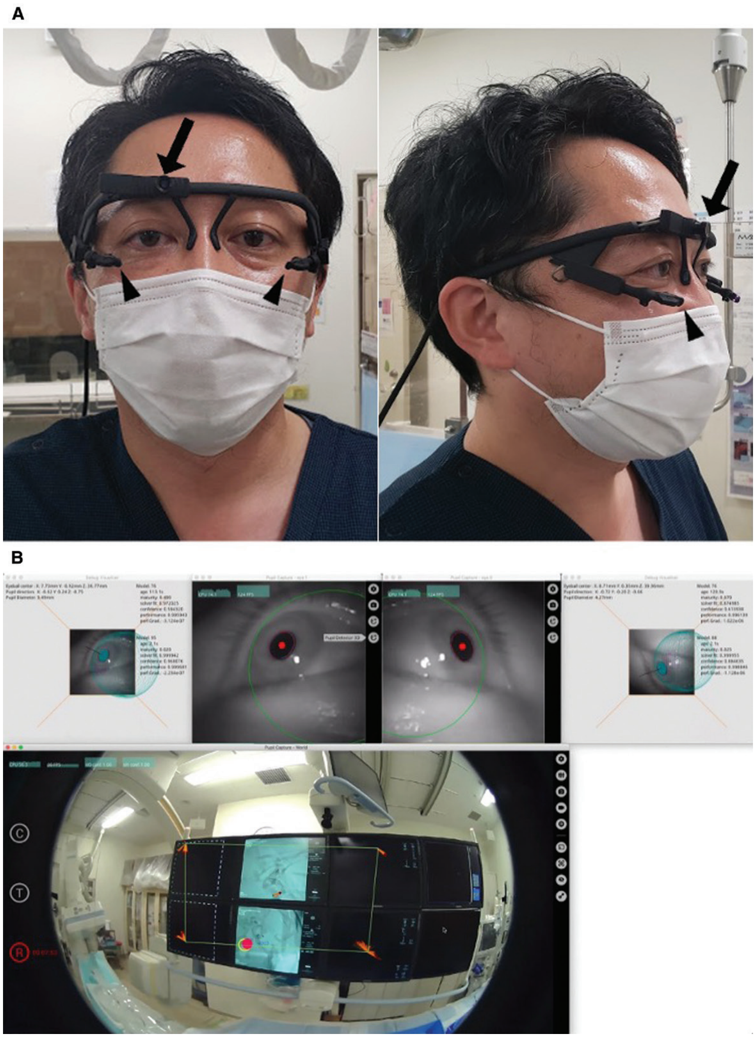

Fig. 1 (**A**) Attachment of the eye tracker. The visual field was acquired using a world camera (arrows) attached outward to the upper region of the glasses, and the directions of the bilateral eyeballs were measured using two infrared cameras (arrowheads) equipped inward to the bilateral lower regions of the glasses to analyze gaze. (**B**) Images analyzed by software on a computer. The information of pupil position acquired by the infrared cameras was digitized as pixel position information on the image (upper row). Regarding the gaze position, the gazed region can be objectively evaluated by superimposing with the visual field image acquired by the world camera (lower row).

Results

Two, three, and two of the seven subjects were classified into the Expert, Trainee, and Novice groups, respectively (**Table 1**). The Expert group was composed of one instructor and one specialist certified by the Japanese Society for Neuroendovascular Therapy. The mean numbers of years exclusively engaged in neuroendovascular treatment were 21, 5, and 1.25 years in the Expert, Trainee, and Novice groups, respectively. Gaze analysis in the target procedure period was possible in all subjects.

Procedure 1: Microcatheter navigation

The mean operative time of microcatheter navigation to the aneurysm was 58 seconds in the Expert group, 204 seconds in the Trainee group, and 160 seconds in the Novice group. The mean ratios of gaze at the AP views, LR views, and out-of-screen were 90.3, 6.1, and 2.0%, respectively, in the Expert group and 89.8, 4.4, and 5.1%, respectively, in the Trainee group. In contrast, they were 59.2, 25.5, and 12.7%, respectively, in the Novice group showing that the Novice group tended to look at the LR view and out-of-screen longer. The durations of single gaze at the AP view were 7.2, 17.2, and 6.1 seconds in the Expert, Trainee, and Novice groups, respectively, showing that the Trainee group tended to gaze at the AP view longer in single gaze. The durations of gaze at the LR view (Expert group: 0.8 seconds, Trainee group: 0.7 seconds, and Novice group: 3.5 seconds) and out-of-screen (Expert group: 0.3 seconds, Trainee group: 0.5 seconds, and Novice group: 1.1 seconds) in single gaze tended to be longer in the Novice group. The mean number of gaze movements per minute between the AP and LR view monitors was 8 in the Expert group, whereas it was 3 and 3 in the Trainee and Novice groups, respectively, showing that the Expert group frequently moved their gaze between the AP and the LR monitors (**Table 2**).

Table 1 Demographics of participants

Group	Subject no.	Board certified	Years of performing neurointervention	Experience cases of microcatheter navigation (main operator)	Experience cases of brain aneurysm coiling (main operator)
Novice	1	No	0.5	0–5	0
	2	No	2	0–5	0
Trainees	3	No	5	10–50	0–5
	4	No	6	50–100	0–5
	5	No	8	50–100	0–5
Expert	6	Yes	12	200–500	50–100
	7	Yes	30	>2000	>1000

Table 2 Summary of eye-tracking data in each group

	Expert (n = 2)	Trainee (n = 3)	Novice (n = 2)
Microcatheter navigation			
Operating time (mean, sec)	58.0	204.3	160.0
Percentage of fixation duration (mean, %)			
AP view	90.3%	89.8%	59.2%
LR view	6.1%	4.4%	25.5%
Out of screen	2.0%	5.1%	12.7%
Duration per one time fixation (mean, sec)			
AP view	7.2	17.2	6.1
LR view	0.8	0.7	3.5
Out of screen	0.3	0.5	1.1
Saccade between screens (mean, numbers per minute)			
AP to LR	4	2	2
LR to AP	4	1	1
Total	8	3	3
Coil embolization			
Operating time (mean, sec)	108.0	158.3	107.0
Percentage of fixation duration (mean, %)			
AP view	81.5%	94.4%	77.5%
LR view	17.3%	3.6%	8.3%
Out of screen	0.9%	1.5%	14.0%
Duration per one time fixation (mean, sec)			
AP view	4.5	24.9	8.9
LR view	1.1	0.4	1.2
Out of screen	0.1	0.2	1.2
Saccade between screens (mean, numbers per minute)			
AP to LR	9	2	4
LR to AP	8	1	2
Total	17	3	6

AP: anterior–posterior; LR: lateral

Procedure 2: Coil insertion

The mean operative time of coil insertion was 108, 158, and 107 seconds in the Expert, Trainee, and Novice groups, respectively. The mean ratios of gaze at the AP and LR view monitors and out-of-screen during the procedure were 81.5, 17.3, and 0.9%, respectively, in the Expert group, showing that the AP view was gazed at as a main image and the LR view was gazed at as a sub image. On the other hand, in the Trainee group, the ratios of gaze at the AP and LR views and out-of-screen were 94.4, 3.6, and 1.5%, respectively, showing that the procedure was performed by mostly gazing at only the AP view. In the Novice group, they were 77.5, 8.3, and 14.0%, respectively, showing that the duration of looking out-of-screen was longer than those in the other two groups. The duration of single gaze at the AP view tended to be longer in the Trainee group (Expert group: 4.5 seconds, Trainee group: 24.9 seconds, and Novice group: 8.9 seconds), whereas the time looking

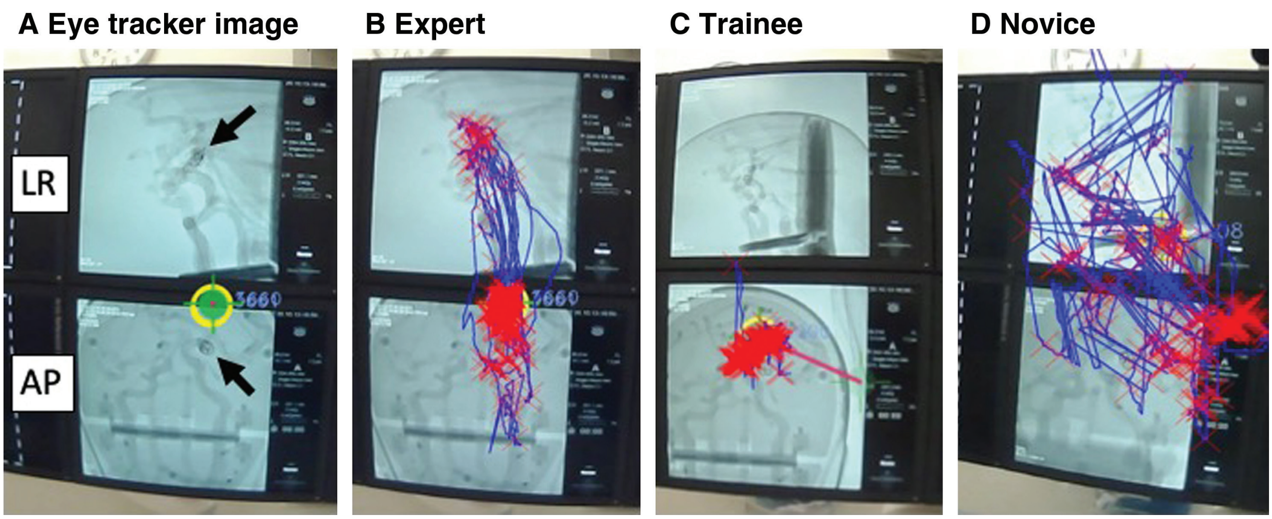

Fig. 2 Gaze during coil insertion in a representative case. (**A**) Image acquired by the eye tracker. The lower and upper rows present the AP view and LR view, respectively, and the region marked with a circle indicates the region gazed at. The position of the target aneurysm of the procedures is shown with arrows. (**B**–**D**) Locus of gaze in the representative case in each group. The red X marks and blue lines represent the gazed position and gaze movement, respectively. AP: anterior–posterior; LR: lateral

out-of-screen tended to be longer in the Novice group (Expert group: 0.1 seconds, Trainee group: 0.2 seconds, and Novice group: 1.2 seconds). The numbers of gaze movements between the AP and the LR monitors were 17, 3, and 6 per minute in the Expert, Trainee, and Novice groups, respectively, showing that the gaze moved frequently between the monitors in the Expert group (**Table 2**).

Representative cases of the Expert, Trainee, and Novice groups during coil insertion are shown in **Fig. 2**. The gaze positions were plotted, and the locus of the gaze was presented as a line and superimposed with the image of the visual field acquired by the world camera. The Expert group performed the procedure using the AP view as a main operation screen and the LR view as a subscreen. No region was gazed at other than the region around the aneurysm and the microcatheter-detachment point, and the gaze moved only between the AP and LR views of the aneurysm without gazing at unnecessary regions. On the other hand, the Trainee group gazed only at the surrounding of the aneurysm in the AP view and the LR view was mostly not used. In the Novice group, the visual point was not fixed and unnecessary regions other than the aneurysm and microcatheter were also gazed at. By superimposing the visual filed image acquired by the front camera and gaze, differences in gaze among the Expert, Trainee, and Novice groups could be visually evaluated.

Discussion

Based on the results of this study, it was possible to detect where was gazed at during neuroendovascular treatment using the eye tracker. Gaze during the procedure differed depending on the treatment experience: in the Novice group, gaze is not fixed and various places including unnecessary places are looked at, the Trainer group concentrates the gaze at one point and cannot keep an eye on the other regions, and the Expert group uses the main and sub views appropriately and does not gaze at unnecessary places, being characteristics.

For coil embolization of a cerebral aneurysm, it is important to acquire necessary information from an appropriate working projection view to safely execute treatment. It is necessary to collect information, such as whether the neck and the parent artery of aneurysm are separated, whether the region to be embolized or not is clear, and whether the state of artery branching from the neck of aneurysm can be identified, under an appropriate working projection view.[8] This information may be acquired from the images of either the AP or the LR view, but when information collected from one side alone is insufficient, it is necessary to acquire information separately from both screens, in which gaze is divided between the AP and the LR views, so that looking at the monitor at an appropriate time is necessary. The use of the eye tracker may have enabled objectively evaluating how the AP and LR views were used differently during coil embolization.

Gaze detection using an eye tracker has recently been attracting attention as a means to pass on the technique of highly skilled persons to beginners. The visualization of gaze by an eye tracker enables extraction of common and different points of gaze corresponding to the technical level and experience. In addition, gaze analysis of highly skilled operators enables its utilization for procedural manuals and working instructions. Technology inheritance and education using the eye tracker have been utilized in the operation procedures of factories[9] and construction hazards.[10] Similar gaze analysis during working has been also reported in the medical field. Wilson et al. compared groups with and without the use of the gaze of highly skilled operators as an educational material in the education of laparoscopic surgery in beginners and observed that the education effect was superior in the group in which the gaze of highly skilled operators was used for education.[11] In addition, learning about the gaze of highly skilled operators using an eye tracker also influenced in beginners not only learning where to look but also how behave. The sites gazed at by highly skilled operators during treatment are those to be paid attention to during treatment, and learning the highly skilled gaze pattern enables the visual learning of points to pay attention to during treatment.

There have been several reports on differences in the gaze due to the experience in surgery using an eye tracker in fields other than neuroendovascular treatment. In a study on the detection of gaze on a monitor during laparoscopic surgery using an eye tracker, the site gazed at during surgery was different between highly skilled and novice operators, and the gaze was also different when they reviewed the surgical video.[6] Matsumoto et al. investigated whether gaze is different in observing head CT between neurologists and control groups using an eye tracker and observed that while the neurologists gazed at a clinically important site, the control group concentrated their gaze at a site visually noticeable but not clinically significant.[4] In a study investigating gaze during cardiac catheterization using an eye tracker, beginners tended to move their gaze along the vascular distribution regardless of the region of the lesion. They tended to gaze at only lesions clarified before treatment and notice no other abnormality.[12] Using the correct gaze may be important to prevent overlooking findings and errors in operation. Regarding neuroendovascular treatment, Shojima et al. performed a preliminary study in which gaze during the coil embolization of a human vascular model was detected using an eye tracker and the gazes of one operator with abundant treatment experience and three operators with no treatment experience could be recorded using the eye tracker.[13] In our study, gaze was measured using the eye tracker in seven neuroendovascular surgeons while performing the same surgical procedure and it was clarified that the differences in gaze due to the experience in the neuroendovascular treatment can be investigated using the eye tracker. Utilization of the eye tracker for education in neuroendovascular treatment is expected.

In this study, the subjects were divided into Expert, Trainee, and Novice groups; differences in gaze were investigated; and a characteristic gaze pattern was noted in each group. In both procedures of microcatheter navigation and coil insertion, the Novice group tended to look out-of-screen for longer compared with the other two groups. In previous studies investigating gaze during surgery of inguinal hernia[7] and epidural block injection,[14] highly skilled operators gazed at the surgical field and puncture site, whereas the gaze of beginners was distributed to other regions. Beginners may frequently look at their hands and devices because they are not used to the procedure and devices. Moreover, the Novice group gazed at various sites because they lack knowledge about where they should gaze at and what they should judge. Furthermore, the duration of a single gaze may have been prolonged because they took time to make a judgment from one gaze.

Many studies on gaze using an eye tracker compared Expert and Novice groups, but in our study, a Trainee group with experience to some extent unlike the Novice group but less experience than that of the Expert group was investigated as an intermediate group. Differences in gaze between the Expert and Trainee groups were small in the microcatheter procedure and large in coil insertion, and this may have been due to less experience of coil insertion in the Trainee group, although they had experience of the microcatheter procedure to some extent. During coil insertion, the Expert group confirmed the AP and LR views with a good balance, but the Trainee group concentrated only on the AP view. Since the Trainee group had less experience of coil insertion, they may have concentrated on the region mainly looked at during coil insertion, losing room to look at other regions.

There are several limitations of this study. First, the number of subjects was only seven, being small, so that statistical verification could not be performed. In addition, the subjects of this study were physicians of the same institution. Since there were individual differences in gaze during treatment even in highly skilled operators, detailed variations may be analyzed by collecting data from physicians of various institutions. Second, where on the monitor was being gazed at could not be closely investigated. The aneurysm model in this study was projected to an about 2-cm size on each screen. To judge which of the deep region or neck side of the aneurysm is looked at, accuracy capable of discriminating gaze within 2 cm 70–80 cm ahead is necessary. Discrimination of gaze within a small range is difficult using the currently used wearable eye tracker, but it is expected to become possible with the development of devices. Finally, this study used a human vascular model, not actual aneurysm treatment. A state close to the actual treatment may be reproduced in the human vascular model, but verification of whether similar results can be acquired in actual treatment is necessary. Gaze measurement in actual treatment is capable of accurately investigating gaze during treatment, and the point to pay attention to can be visually understood by preparing a video with the gaze pattern of highly skilled operators. Furthermore, with the addition of an explanation of the reason and background of moving the gaze by highly skilled operators, the point of treatment becomes easier to understand than that in previous lecture videos as an educational material.

Conclusion

It was possible to analyze gaze during neuroendovascular treatment using an eye tracker. Using the eye tracker, the sites gazed at during treatment can be objectively extracted, which clarifies differences in gaze corresponding to differences in treatment experience and technical level. By understanding the gaze of highly skilled operators, what they pay attention to during treatment can be visually learned, being expected to be utilized for the education of neuroendovascular treatment in the future.

Acknowledgments

A part of this study was supported by Japan Science and Technology Agency (JST) CREST "Behavior change and harmonious collaboration by experiential supplements" (JPMJCR16E1). We are grateful to Yasuyuki Kaga (EPS Corporation) for giving us statistical advice in preparation of this report.

Disclosure Statement

The authors declare no conflicts of interest.

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