ANALYSIS OF GAZE BEHAVIOR AND ELECTROMYOGRAPHY DURING NIHON KENDO KATA

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This study aims to elucidate whether the gaze strategies of performers in *Nihon Kendo kata* and the muscle activity involved in gripping the sword depend on skill level. Six college-aged students participated, three having over 14 years of experience and the remaining three being novices. A wearable eye-tracking device was employed, and the surface electromyography (EMG) of the flexor digitorum profundus was recorded. We calculated objective features and applied a two-way ANOVA. As a result, a main effect of the expertise level was observed for the number and duration of fixations, the average acceleration obtained from eye movement, and the normalized time-averaged values from EMG ($p<.01$). These findings suggest that distinct gaze strategies and muscle activation patterns indicate expertise in Kendo, thereby offering valuable insights for instructional practices.

KEYWORDS: Kendo, eye movement, electromyogram.

INTRODUCTION: Kendo matches are conducted on a square or rectangular court with sides measuring 9 to 11 meters. The engagement with the opponent is intense, requiring the constant grasp of abundant information and continuous accurate situational judgment. The utilization of vision is expressed by the term '*Metsuke*,' highlighting the significance of the eyes in guidance. Particularly, broadly observing the opponent's eyes (mind) without being misled by their movements is called '*Enzan no Metsuke*.'

Nihon Kendo Kata is an exercise for practicing sword techniques, serving as the foundation for acquiring the fundamental principles of correct sword usage (Budden, 2023). This is also applicable to promotion examinations. Instruction based on objective and quantitative insights can contribute to the effective enhancement of competitive Kendo skills.

As for previous studies on gaze strategies in open-skill sports, studies have been conducted in various contexts, such as basketball, soccer, badminton, and more. In eye movements, there are rapid movements like saccades (>100 [deg/s]) and slower movements called pursuit, among others (Lappi, 2016). The latter are voluntarily controlled in a closed-loop manner based on prediction and experience. Finding common eye movement strategies among experienced practitioners, even in slower movements of kendo forms than actual matches, may effectively support improvement. However, objective and quantitative insights into gaze distribution strategies and muscle exertion for performers of Japanese Kendo Kata still unclear.

Therefore, this study aims to investigate whether there are differences in gaze behaviour and muscle exertion in the upper-arm skeletal muscles holding the wooden sword between novices and skilled practitioners using wearable measurement devices.

METHODS: Six male college-aged students (21-22 yr) participated as experimental subjects. Among them, three had over 14 years of experience and were classified as the skilled group. The remaining three were novices. One experienced group member was left-handed, while the others were right-handed.

The eye-tracking device was the GPE4 (Gazo Co. Ltd, Japan). This device includes an infrared camera reflecting the eyeball and a field camera capturing the field of view. The field camera captures a visual angle of 120 degrees horizontally, and 65 degrees vertically, and this perspective is recorded in full high-definition size (1920×1080 [px]). Gaze data were recorded with a frame rate set to 25 [fps] (sampling interval Δt = 1/25 [s]). Additionally, surface electromyography (EMG) of the flexor digitorum profundus muscle, which is involved in gripping the wooden sword and muscle exertion during strikes, was measured using BITalino (r)evolution (PLUX, Portugal). EMG recording was conducted at a sampling frequency of 1000 [Hz].

After equipping each measurement device on the subjects, we first instructed the participants to perform a maximum voluntary contraction for five seconds at the site where EMG was measured. Then, the participants performed the first (*Ipponme*), second (*Nihonme*), and third (*Sanbonme*) Nihon Kendo Kata forms. For each form, the subjects acted out the roles of Uchitachi and Shitachi once each. Considering the participants performing two roles for three types of forms and the burden on the participants of wearing a laptop for recording eye-tracking data, the number of trials for each was limited to one. In each form, the duration from the start to the end time was divided into segments, with 0% and 100% representing the initiation and completion, respectively. The elapsed time was normalized. Specifically, 20% indicated the initiation of the striking motion in '*Uchitachi*,' and 40% indicated the initiation in '*Shitachi*.' To quantify eye movement, we first obtained the displacement $\Delta r(t)$, calculated from the coordinates ($x(t)$, $y(t)$) at each time point with a sampling interval Δt, and the velocity $v(t)$ according to the following equations.

$$v(t) = \frac{\Delta r(t)}{\Delta t}, \quad \Delta r(t) = \sqrt{(x(t) - x(t - \Delta t))^2 + (y(t) - y(t - \Delta t))^2}$$

Then, the acceleration, $a(t) = \Delta v(t)/\Delta t$, was calculated.

Furthermore, a gaze fixation was defined as a state where the gaze velocity remained at or below 10 [deg/s] for 120 [ms].

The raw EMG data was passed through a fifth-order Butterworth filter with a cutoff frequency of 20 Hz and then rectified. The same processing was applied to the wooden sword grip before the trials, and the maximum amplitude value was set as 100%, normalizing the amplitudes during the trials. Additionally, a moving average processing was applied using 10 points, ranging from the past 5 points to the future 4 points (nEMG).

Variables related to gaze, including the number of fixations (n_{Fix}), duration of fixation (T_{Fix}), time-averaged velocity ($\overline{v(t)}$), and time-averaged acceleration ($\overline{a(t)}$), were calculated from the gaze data. Time-averaged nEMG, $\overline{EMG}$, was also calculated was calculated by averaging from the onset to the end of the nEMG amplitude. Using SPSS Statistics ver. 29, a two-way analysis of variance (ANOVA) was conducted to compare these values, with expertise level (novice/skilled) as the between-subject factor and role (*Uchitchi*/*Shitachi*) as the within-subject factor, setting the significance level at 5%.

RESULTS: We observed the eye gaze trajectories by correlating them with the first-person perspective videos of the participants. Novices exhibited more extensive eye movements, while skilled participants focused on the opponent's face. Figure 1 (Top) illustrates the gaze velocity as a function of normalized time during the role of *Uchitachi*, with error bars representing each group's standard deviation (SD). Overall, novices tend to have higher gaze velocities suggesting less focused as intended compared to skilled athletes.

Figure 1 (Bottom) depicts the time waveform of nEMG, with error bars indicating the SD for each group. The amplitude of nEMG is generally higher for novices than skilled. However, during the striking phase of *Shitachi* (around 40%), skilled tended to exhibit higher values, indicating a rhythmically varied behaviour in skilled participants.

Table 1 presents the aggregated results for various features in the *Nihon Kendo Kata Ipponme*. The mean and SD of gaze fixation count for novices performing *Uchitachi* were 0.330±0.577, and for *Shitachi*, it was 1.670±2.887. Skilled participants showed values of 65.67±9.018 for *Uchitachi* and 58.00±18.76 for *Shitachi*, indicating a significant main effect of expertise (F (1,4) =81.28, p=0.001). For duration of fixation, T_{Fix}, novices had values of 0.578±1.002[s] for *Uchitachi* and 0.688±1.192[s] for *Shitachi*. In contrast, skilled had 9.868±1.275[s] for *Uchitachi* and 8.225±1.807[s] for *Shitachi*, showing a significant main effect of expertise (F (1,4) =163.7, p<0.001). Regarding velocity, $\overline{v(t)}$, novices recorded 30.74±12.41[deg/s] for *Uchitachi* and 25.50±0.845[deg/s] for *Shitachi*, while skilled showed 9.467±5.609[deg/s] for *Uchitachi* and 15.94±13.89[deg/s] for *Shitachi*. Acceleration, $\overline{a(t)}$, for novices was 890.4±376.0[deg/s^2] for *Uchitachi* and 742.0±34.93[deg/s^2] for *Shitachi*, while skilled had 69.57±41.20[deg/s^2] for

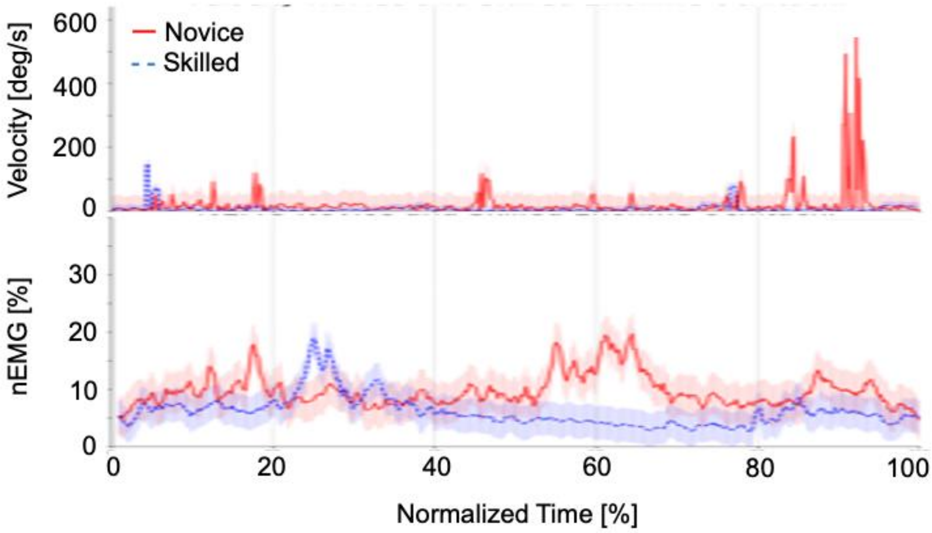

Figure 1: (Top) Gaze velocity as a function of normalized time during Uchitachi, (Bottom) nEMG as a function of normalized time during Uchitachi in Ipponme.
***Note*. Red Solid line = Novice. Blue Dashed line = Skilled.**

Uchitachi and 116.3±103.4[deg/s^2] for *Shitachi*, demonstrating a significant main effect of expertise (F (1,4) =33.38, p=0.004). The average nEMG for novices was 9.637±4.819 for *Uchitachi* and 10.67±4.791 for *Shitachi*, while skilled recorded 5.657±0.684 for *Uchitachi* and 7.740±3.467 for *Shitachi*, indicating a significant main effect of expertise (F (1,4) =36.17, p=0.004). None of these features showed a significant main effect or interaction with the role.

Table 1: Comparison based on ANOVA for Features of Gaze and EMG

Vari-able	Level (Group)	Role				ANOVA			
		Uchitachi		*Shitachi*					
		M	*SD*	*M*	*SD*	Source	*F*	*p*	η^2
n_{Fix}	Novice	0.330	0.577	1.670	2.887	G	81.284	.001	.953
	Skilled	65.670	9.018	58.000	18.735	R	0.358	.582	.082
						I	0.724	.443	.153
T_{Fix} [s]	Novice	0.578	1.002	0.688	1.192	G	163.71	< .001	.976
	Skilled	9.868	1.275	8.225	1.807	R	0.909	.394	.185
						I	1.188	.337	.229
$\overline{v(t)}$	Novice	30.743	12.409	25.497	0.845	G	5.519	.079	.580
[deg/s]	Skilled	9.467	5.609	15.937	13.894	R	0.019	.898	.005
						I	1.705	.262	.299
$\overline{a(t)}$	Novice	890.39	376.02	742.02	34.93	G	33.384	.004	.893
[deg/s^2]	Skilled	69.573	41.202	116.32	103.43	R	0.254	.641	.060
						I	0.936	.388	.190
$\overline{EMG}$	Novice	9.637	4.819	10.667	4.791	G	36.169	.004	.900
	Skilled	5.657	0.684	7.740	3.467	R	67.777	.500	.944
						I	7.758	.050	.660

Note. *M* = Average. *SD* = Standard deviation. G = Group. R = Role. I = Interaction.

DISCUSSION: Using wearable gaze measurement devices and EMG measurement devices, we quantitatively investigated gaze behaviour and muscle exertion in the arm holding the

wooden sword during the movements of Japanese Kendo Kata. We examined whether these features differ between novice and skilled participants.
Based on the results regarding eye movements, novice participants tended to shift their gaze to areas other than the face, such as the tip of the sword or the hand. In contrast, skilled participants generally maintained focus on the face. Quantitative analysis of eye movement velocity and acceleration revealed a significantly higher tendency among novices. It is presumed that novices, lacking cues for the opponent's next move, busily shifted their gaze between the tip of the sword and the hands to acquire information. However, novices frequently performed voluntary eye movements (pursuit) and could only track at speeds up to around 30 [deg/s]. Considering the results of this study (Figure 1 (Top)), it is difficult to track the visual target, and consequently, allocating attention resources for predicting the next move is challenging. On the other hand, skilled participants maintained their gaze on specific positions. In Kendo and any competitive sport involving interpersonal interactions, higher-level players are required to execute rapid movements and responses. To cope with this demand, players need to anticipate while playing. Skilled individuals, by understanding the concept of '*Enzan no Metsuke*,' are presumed to utilize their peripheral vision to broadly observe the entire situation while maintaining focus on the opponent's face through Kendo kata, thereby predicting the opponent's next move.
These results suggest that skilled participants possess a visual exploration strategy specific to their expertise, as implied by previous research (Land & McLeod, 2000). Skilled participants may make rapid and accurate decisions by focusing on specific signals or movements. Additionally, skilled participants embodying the principles of Kendo, such as '*Enzan no Metsuke*,' adopted a strategy of acquiring information from various parts of the opponent simultaneously, implying that skilled excel in acquiring information from the peripheral field of view.
We measured and evaluated the EMG activity of the flexor digitorum profundus used for gripping the wooden sword. As a result, novices exhibited sustained discharge, while skilled individuals showed consistently lower levels, with brief spikes during strikes. This underscores the importance of understanding pacing in Nihon Kendo Kata practice. Furthermore, utilizing muscles with varying intensity generates significant force during strikes. These findings reflect an understanding of such guidance. Thus, the importance of instructing novices on the significance of relaxation becomes evident. The analysis for the *Nihonme* and *Sanbonme*, which are additional exercises, will be conducted similarly to the presented analysis.

CONCLUSION: This study quantitatively investigated the differences in gaze distribution and skeletal muscle exertion in the upper arm holding the wooden sword between novice and skilled college-aged athletes practicing Japanese Kendo Kata, one of the martial arts. Skilled participants maintained their focus on a specific position (the opponent's face) when performing either role. This result suggests an understanding of the martial arts doctrine, precisely the concept of '*Enzan no Metsuke*,' among experienced practitioners. Additionally, novices maintained tension in the upper arm during the technique. This result indicates a need for more rhythm in muscle exertion compared to experienced practitioners.
The results of this study may contribute to improving efficiency in Kendo and, ultimately, enhance the competitive prowess in martial arts.

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