Quantitative Ultrasound for Weight-Training Assessment

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I. INTRODUCTION

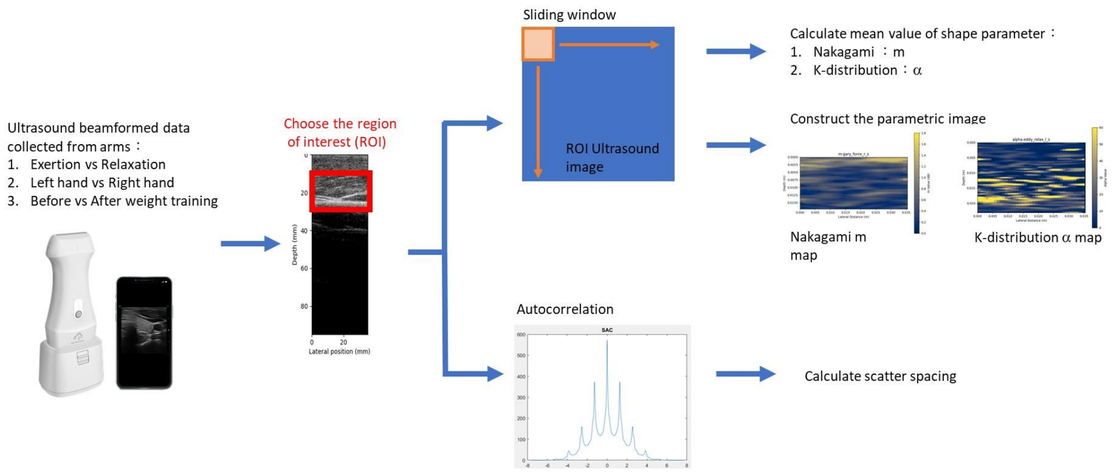
Research Motivation

- In recent years, the rise in health awareness and changes in lifestyle have made fitness a mainstream cultural element.
  → Developing an device to monitor fitness results is important.
- The research results show that quantitative ultrasound using Nakagami distribution, K distribution, and Autocorrelation can clearly demonstrate the changes in muscle fibers and cells after weight training.

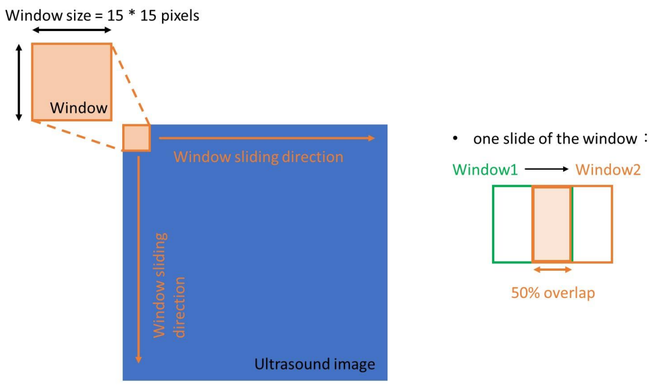
Research Object and Procedure

- The purpose is to detect the differences before and after weight training using portable ultrasound, allowing people to better adjust their fitness routines

Experimental Procedure Diagram



Operating method of sliding window technique



Ultrasonic Probe Specifications

Sampling rate	25.6 MHz
Center frequency	6.5 MHz
Focus depth	20 mm
Number of scan line	128
sound velocity	1540 m/s
pitch distance	3 mm
detection depth	5mm-100mm

II. EXPERIMENTAL METHOD

Acquire ultrasound backscatter data and use beamforming data for processing and subsequent analysis.

- **Nakagami distribution :**

Nakagami distribution effectively represents pre-Rayleigh, Rayleigh, and post-Rayleigh distributions. According to the Nakagami model, the probability density function (PDF) is:

$$f_r(r|m,\Omega) = \frac{2m^m}{\Gamma(m)}\Omega^{2m} r^{2m-1}\exp\left(\frac{-mr^2}{\Omega}\right)$$

$$m = \frac{E[R^2(r)]}{(E[R(r)])^2} \qquad \Omega = \frac{E[R(r)]}{2}$$

Γ() : gamma function,
E() : statistical mean.
Ω : shape parameter
m : scale parameter.

- **K distribution:**

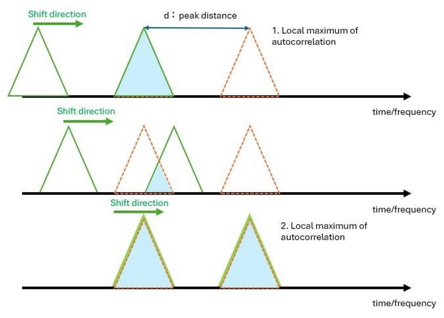
The Nakagami distribution mentioned above is commonly used to describe signals in environments with high scattering uniformity. However, in more complex scattering environments, the K distribution demonstrates its superiority. According to the K distribution model, the PDF is:

$$f_r(r|\alpha,\lambda) = \frac{4}{\sqrt{\lambda}\Gamma(\alpha)}\left(\frac{r}{\sqrt{\lambda}}\right)^{\alpha} k_{\alpha-1}\left(\frac{2r}{\sqrt{\lambda}}\right)$$

Γ() : gamma function,
K_n : modified Bessel function of the second kind
α : shape parameter
λ : scale parameter.

- **Autocorrelation**

Autocorrelation evaluates the spacing between peaks of a single signal. This is done by shifting the signal so that peaks align with peaks, resulting in local maxima. Measuring the average spacing of these local maxima allows for the estimation of scatterre spacing values.



Orange line：original signal
Green line：shift signal
Blue area: overlapping area of original signal and shift signal

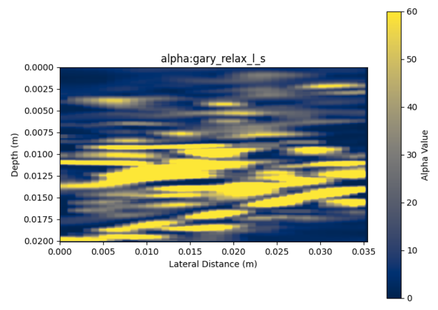
- Autocorrelation：the overlapping area of original signal and shift signal
- We can measure the distance of two local maximum to calculate the scatter spacing

$$d = \frac{v}{2\Delta f}$$

d : spacing between scatterer
v : the speed of sound
Δf : the average spacing between peaks.

III. EXPERIMENTAL RESULTS

Reconstruct an image using parameter values estimated by various algorithms.



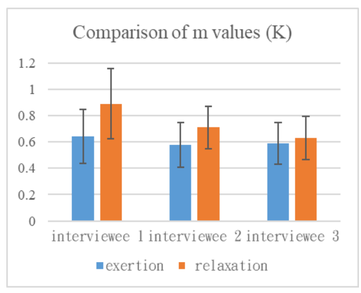
The image reveals a different appearance compared to the B-mode image, highlighting details that the B-mode could not capture.

- The yellow areas in the image represent higher parameter values, indicating a higher concentration of cells in these regions.
- the blue areas denote lower parameter values, indicating fewer cells in those areas.

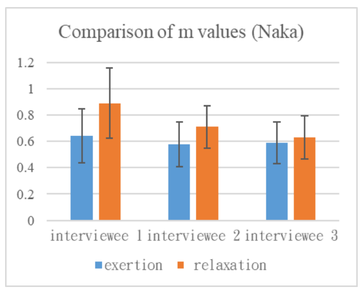
Comparison of parameters between exertion and relaxation

Collect data on biceps exertion and relaxation, and compare and analyze the parameters estimated using Nakagami distribution, K distribution, and Autocorrelation .

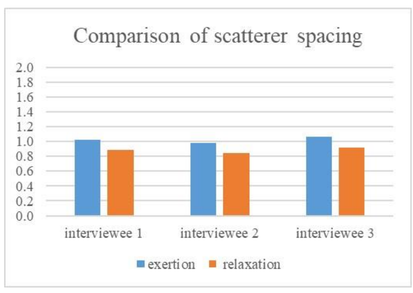
K distribution



Nakagami distribution



Autocorrelation

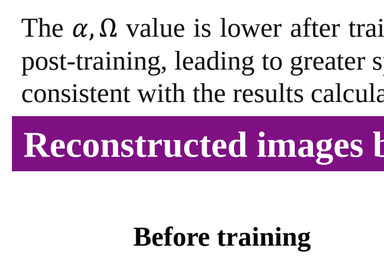


The α and Ω value is always higher during muscle relaxation than during exertion. During exertion, muscle fibers are stretched, leading to increased spacing between cells. Consequently, the number of scatterers per unit area decreases, resulting in a reduction in the shape parameter α, Ω. This aligns with the results calculated by our autocorrelation analysis.

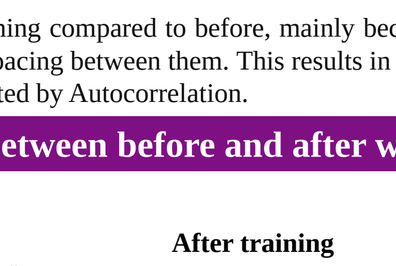
Comparison of parameters between dominant and non-dominant hand.

Collect data on the dominant and non-dominant hand, and compare and analyze the parameters estimated using Nakagami distribution, K distribution, and Autocorrelation.

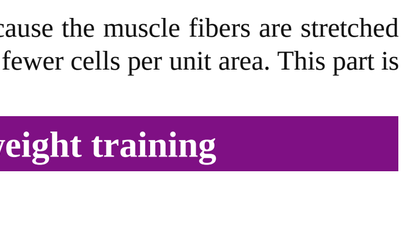
K distribution



Nakagami distribution



Autocorrelation

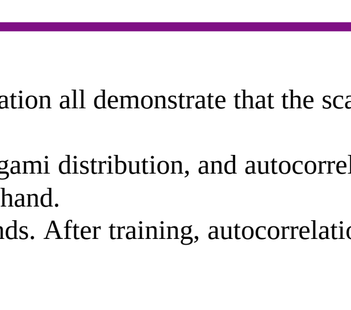


During exertion, it is noticeable that the α, Ω value of the dominant hand significantly decreases. This is mainly because the dominant hand is typically more trained, leading to greater spacing between muscle fibers and, consequently, fewer cells per unit area. This part is consistent with the results calculated by Autocorrelation.

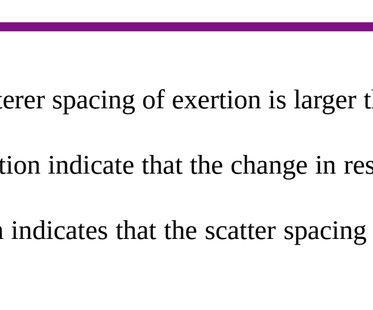
Comparison of parameters between before and after weight training

Collect data before and after weight training, and compare and analyze the parameters estimated using Nakagami distribution, K distribution, and Autocorrelation.

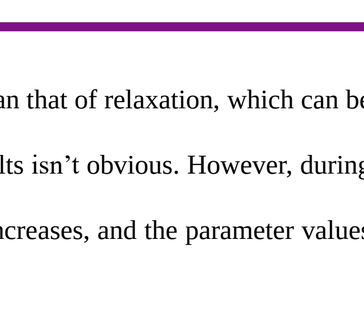
K distribution



Nakagami distribution



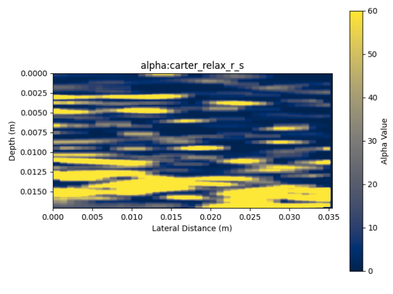
Autocorrelation



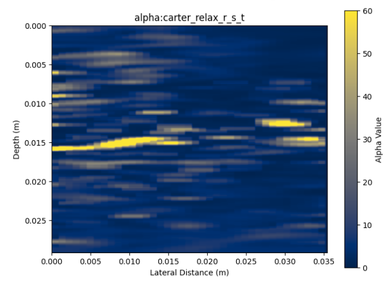
The α, Ω value is lower after training compared to before, mainly because the muscle fibers are stretched post-training, leading to greater spacing between them. This results in fewer cells per unit area. This part is consistent with the results calculated by Autocorrelation.

Reconstructed images between before and after weight training

Before training



After training



This indicates that after training, there are lower parameter values due to the increased spacing between muscle fibers, resulting in less yellow areas on the image.

IV. CONCLUSION AND FUTUER WORK

Conclusion

- Analyzing the comparison between exertion and relaxation, the K distribution, Nakagami distribution, and autocorrelation all demonstrate that the scatterer spacing of exertion is larger than that of relaxation, which can be verified using autocorrelation.
- In analyzing the comparison between dominant and non-dominant hands, during relaxation, the K distribution, Nakagami distribution, and autocorrelation indicate that the change in results isn't obvious. However, during exertion, all three methods show that the scatter spacing of the dominant hand is larger than that of the non-dominant hand.
- Analyzing the comparison before and after weight training, the K distribution and autocorrelation exhibit similar trends. After training, autocorrelation indicates that the scatter spacing increases, and the parameter values of the K distribution decrease due to the reduced number of scatters per unit area.

Future Work

- Developing a method for long-term tracking and quantification of weight training effectiveness.
- Developing an app for rehabilitation to track the recovery state, which can apply better treatment.