

**Final Project: Daily Use of Grip Strength Trainer and Improvement
in Grip Strength**

Section No: #1, Group No: 8

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I. ABSTRACT

This experiment investigates the effect of daily low-load isometric resistance training on hand grip strength (HGS) in terms of maximum force and endurance in young adults. Participants were divided into two groups: a training group and a non-training group. The training group performed daily one minute isometric squeezes of a grip strength trainer. Grip strength data was collected using a Vernier hand dynamometer and recorded electronically through LoggerPro for analysis. Each participant completed a single 60-second maximum effort trial, allowing for evaluation of both peak and mean grip force. It is expected that the training group will demonstrate an increase in grip strength and endurance compared to the control group. Analysis of the results indicated that the training group experienced an increase in mean sustained grip strength over time ($p = 0.0277$), however the changes in maximum force were not statistically significant ($p = 0.058$). There was no measurable improvement in endurance due to the time constraints. High variability and small sample size also limited the strength of the data. The data trends show that short-term training may improve grip strength.

II. INTRODUCTION AND BACKGROUND

Hand grip strength (HGS) is an important measure of physical capability. Everyday activities such as carrying objects, climbing, and lifting all rely on adequate grip strength, making it a key functional ability. It also plays a role in athletic performance for many sports. HGS is widely used as an indicator of overall health and has been linked to quality of life and long-term outcomes such as injury risk and physical decline [1]. Understanding how grip strength can be improved through simple training methods has both practical and physical relevance.

The objective of this experiment is to investigate how a short-term, low-load isometric training program affects grip strength and endurance in young adults. Specifically, this study compares a training group performing daily squeezing holds of a grip strength training device as seen in Figure 1, to a non-training control group over a two-week period. The primary goal is to determine whether consistent, short-duration training leads to measurable increases in maximum grip force and fatigue resistance over time.



Figure 1: Hand grip strength trainer as used in the training. Image courtesy of Amazon.

Grip strength comes from the coordinated action of muscles in the hand and forearm, and its magnitude depends on both muscular and neural factors. From a physiological standpoint, strength is related to muscle cross-sectional area, meaning that larger muscles are capable of producing greater force [2]. An important factor in overall muscle fatigue is neurological fatigue, where a muscle that is activated for an extended period of time will have less frequent action potentials sent to it, as the brain is trying to protect the muscle from injury. The decline in frequency of these electrical signals causes the muscle output to decrease [3]. In this study, we decided to have participants look away from the screen that is providing live force data so that

we are measuring their total fatigue, both mechanical and physiological, as in everyday life, we are not aware of the exact output of our muscles.

To quantify grip strength, a hand dynamometer is used to measure the force exerted during gripping. In this experiment, participants attempt a maximum-effort squeeze for 60 seconds, allowing both peak grip and average grip force to be evaluated. The maximum grip value represents the maximum force generated, while the average force is relevant for endurance and fatigue behavior over time. This analyzes how strong a participant is and how well they can use that strength for an extended period of time.

Muscle fatigue is an important factor in sustained grip performance and can be described using established models such as Rohmert's law, which suggests that the ability to maintain force decreases over time under continuous load, in other words, muscles don't fatigue linearly. Endurance measurements are expected to show a decline in force throughout each trial. Based on previous studies and theoretical models of strength development, it is expected that participants in the training group will show measurable improvements in both grip strength and endurance, while the control group will exhibit little to no change over the same time period. Our study aims to answer the following: does daily low-load isometric resistance training affect HGS and grip endurance in young adults over a two-week period?

III. METHODS/PROCEDURES

A. Training Program

The training program consisted of a daily isometric grip hold performed using a commercial grip strength trainer (Figure 1) set to a difficulty of 8 out of 10 for the individual. The individual was allowed to choose the resistance of the trainer for themselves, as each participant has different abilities. Each session required participants to squeeze the trainer continuously for one minute. This protocol was selected to provide a short duration resistance exercise that would be challenging but obtainable for a one minute long continued hold.

B. Participant Selection

Participants were recruited from the MCEN 3047 course population and divided into two groups: A training group ($n = 4$; 2 male, 2 female) who performed the daily grip training protocol, and a non-training control group ($n = 9$) who maintained normal daily activity without any structured grip exercise. A training population was initially recruited that included 6 participants, but 2 dropped out partway through the study so their data is not included.

C. Data Collection Procedure

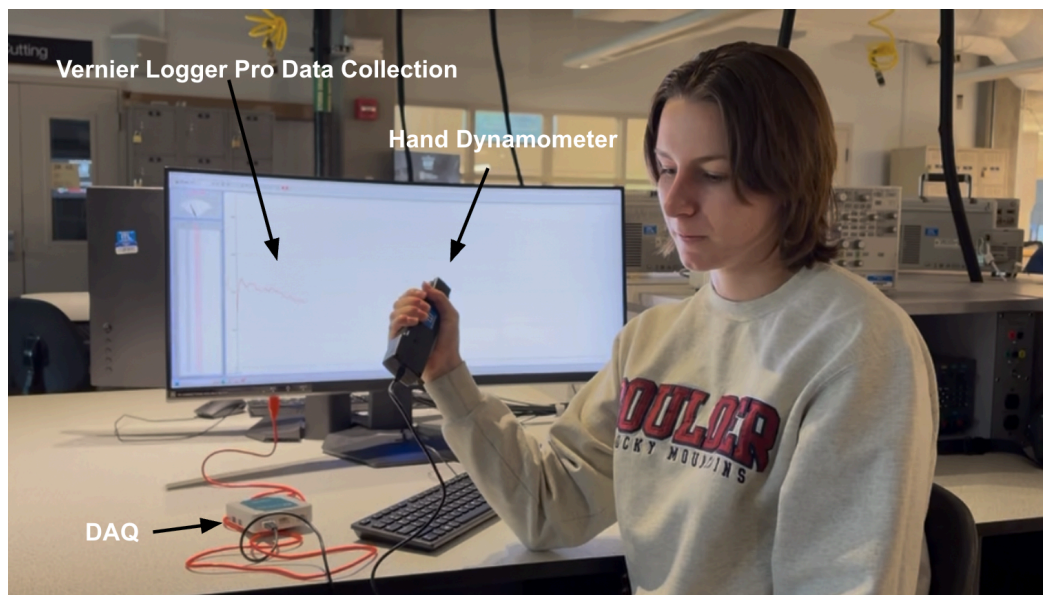
Grip strength was measured using a Vernier Hand Dynamometer (range: 0–600 N, resolution: 0.2159 N) connected to a LabQuest Mini DAQ and recorded in Vernier Logger Pro. It is important to note that the hand dynamometer **does not require calibration**, and a calibration figure is not relevant to the use of this sensor, “You should not have to perform a new calibration when using the Hand Dynamometer. We have set the sensor to match our stored calibration before shipping it.” (Vernier Data Sheet). Further calibration specs are shown in Figure 2.

Specifications

Default calibration (N)	slope: 176.8325 intercept: -19.5057
Default calibration (kg)	slope: 18.0320 intercept: -1.9890
Default calibration (lbs)	slope: 39.7536 intercept: -4.3851
12-bit resolution	0.2159 N
Power	7 mA @ 5VDC
Safety range (maximum force without damage to the sensor)	0 to 850 N
Operational range:	0 to 600 N

Figure 2: Vernier Hand Dynamometer specification sheet.

Each session consisted of a single 60-second maximum-effort isometric grip trial. Standardized positioning was maintained throughout: Participants were seated with their elbow flexed to approximately 90 degrees, forearm resting on the table, and legs uncrossed as seen in Figure 3.

**Figure 3:** Picture of experimental setup. Includes sensor in use and participant in an active trial.

The training group was tested twice per week over the two-week period, while the control group was tested twice total, approximately one week apart. The independent variables in this study were the treatment group and the sex of the participant. The dependent variables were the participant's maximum force and grip strength.

D. Data Processing

Raw force-time signals were processed in MATLAB. To account for the brief ramp-up at the start of each trial, analysis was performed on the 55-second window beginning after the local force maximum recorded within the first 5 seconds. Three metrics were extracted from each trial: maximum force, mean force (average force over the 55-second window), and an endurance metric calculated as the mean force normalized by maximum force from the same trial. A linear rate of change per day was estimated for each metric across each participant's sessions. These rates were then analyzed using a two-factor ANOVA with treatment group and sex as independent variables, and 95% confidence intervals were constructed for each main effect. Although Rohmert's law describes force decay within a single trial as exponential, the rate of strength improvement across training sessions over a two-week period is expected to follow a roughly linear pattern. This early phase approximates the initial slope of a longer term model.

IV. RESULTS

A. Raw Data

A representative force-time curve (before processing) from a single 60-second maximum effort trial is shown in Figure 4. At the onset of each trial, participants rapidly increased grip force to a peak value within the first few seconds. Force then declined in a manner consistent

with Rohmert's law, exhibiting a characteristic exponential decay as muscular fatigue accumulated over the duration of the trial. This pattern was observed across nearly all participants and sessions. To isolate the sustained effort portion of each trial, analysis was restricted to the 55-second window beginning after the local force maximum recorded within the first 5 seconds. Maximum force was taken as the peak value over the full trial, while mean force was computed as the average over this 55-second window. The mean %MVC was then calculated by normalizing mean force to each participant's maximum voluntary contraction, providing a fatigue metric that accounts for individual differences in absolute strength.

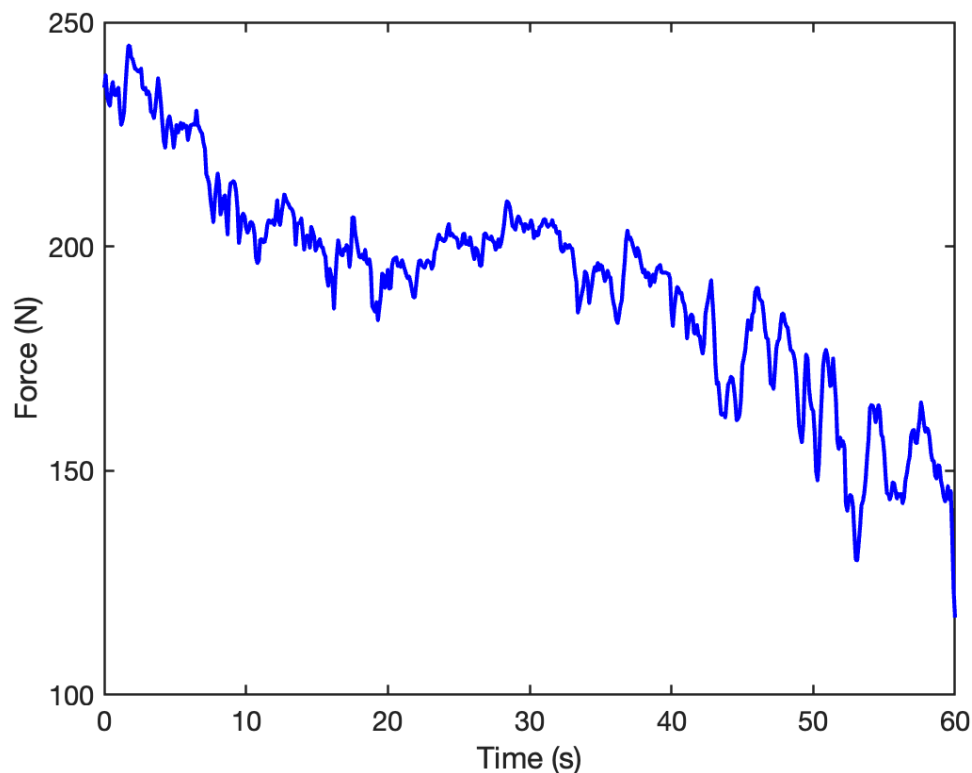


Figure 4: Example force-time data from a single trial. For analysis, the data was trimmed before the first peak and before the end of the trial, resulting in a characteristic 55-second interval for all trials.

B. Baseline Grip Strength

Baseline grip strength data from the first day of the project is visualized in Figure 5. At the 95% confidence level, male participants had higher grip strength than female participants ($\mu_f - \mu_m = -135 \pm 74.4$ N). There was no significant difference in grip strength between training and non-training groups at the onset of the project, before training began ($\mu_{\text{trt}} - \mu_{\text{ctrl}} = -44.2 \pm 175$ N). Baseline grip strength for all participants is significantly lower than expected when compared to international normative data [5], though appears to be in a more reasonable range when limiting comparison to studies that used only electronic dynamometers. Despite the manufacturer's claim that no calibration is required [9], the remainder of this study analyzes within-participant metrics to control for any systemic error in addition to the large range of baseline strength.

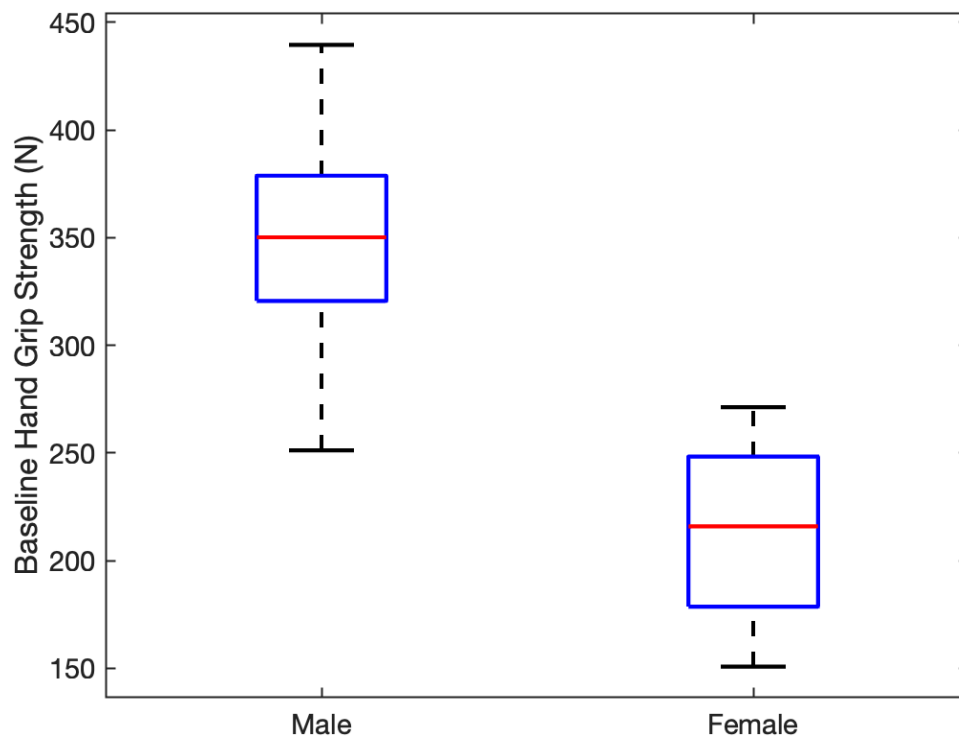


Figure 5: Boxplot of baseline hand grip strength data grouped by sex. No significant difference was found between training and non-training groups at baseline.

C. Maximum Force

Individual maximum force trajectories showed considerable variability across participants over the study period. The two-factor ANOVA on maximum force rate of change yielded a borderline treatment effect ($F = 4.72$, $p = 0.058$) with a 95% confidence interval of $[-0.27, 4.3]$ % baseline per day. Neither sex ($p = 0.819$) nor the sex-by-treatment interaction ($p = 0.357$) reached significance. The confidence interval spanning zero prevents a definitive conclusion, though the direction of the effect is consistent with the theoretical prediction of a positive rate of change in the training group. The uncertainty in these estimates is largely attributable to the small sample size and high inter-individual variability in training response.

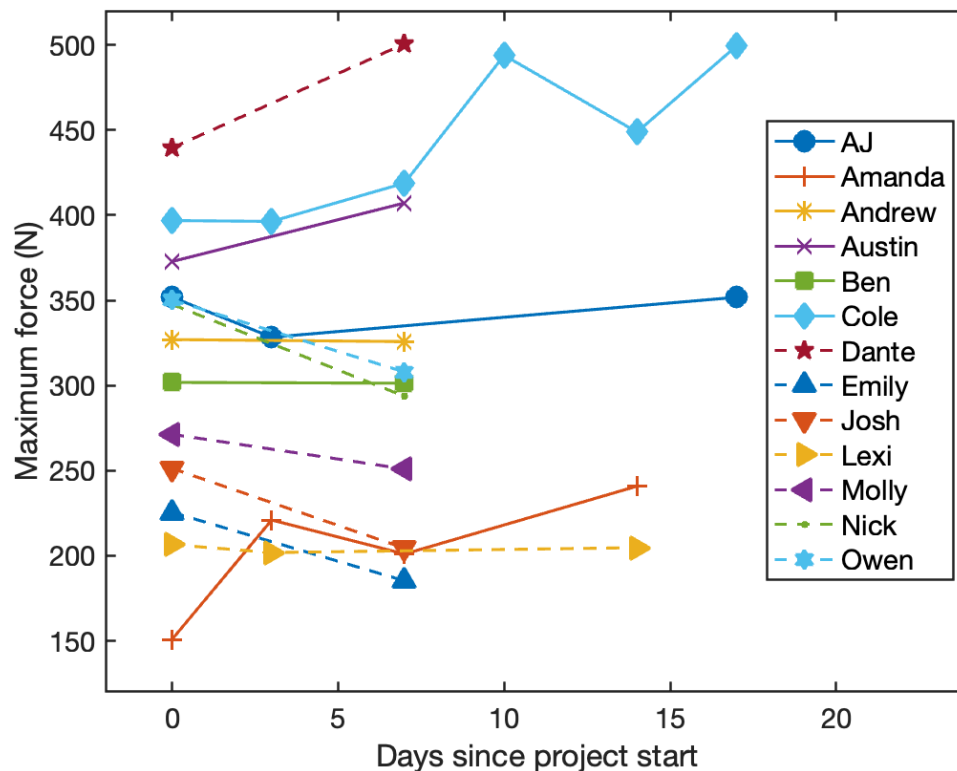


Figure 6: Maximum force in a sustained effort trial plotted over the course of the project for each participant. Participants in the training group were AJ, Amanda, Cole, and Lexi.

D. Mean Force

Mean force showed a statistically significant treatment effect ($F = 6.87$, $p = 0.0277$), with a 95% confidence interval of $[-0.08, 8.2]$ N/day. Trained participants increased their mean sustained force at a higher rate than controls, consistent with the theoretical expectation of a positive linear trend in the training group over this time period. Control participants showed little change, also consistent with expectations. Sex was not a significant predictor ($p = 0.196$), nor was the interaction term ($p = 0.820$). This is the strongest statistical result of the study and suggests that short-term isometric training may improve sustained grip performance even when changes in peak force remain modest. The width of the confidence interval reflects the limited sample size, and a more precise estimate would require additional participants.

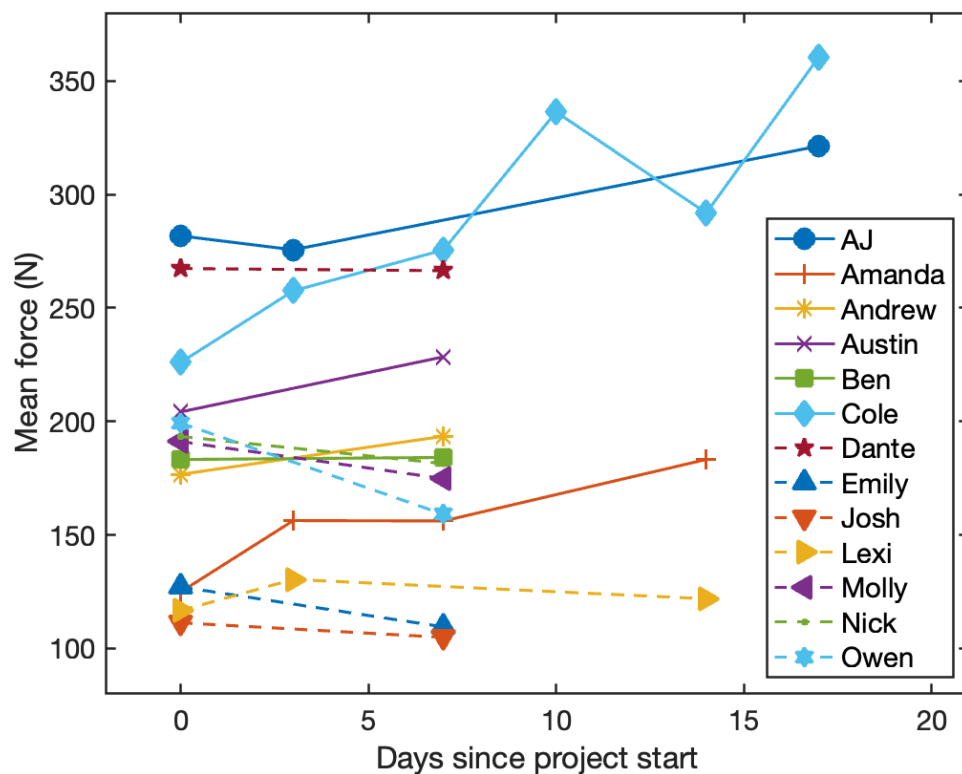


Figure 7: Mean force in a sustained effort trial plotted over the course of the project for each participant. Participants in the training group were AJ, Amanda, Cole, and Lexi.

To illustrate the statistically significant effect observed in this metric, an interaction plot of mean force trajectory for participants grouped by sex and presence of training is shown in Figure 8. The increase seen for both sexes between control and training demonstrates the effect of training on mean force over time. Comparing the slopes of both sexes confirms, at a glance, that there was no observed interaction between participant sex and the training program.

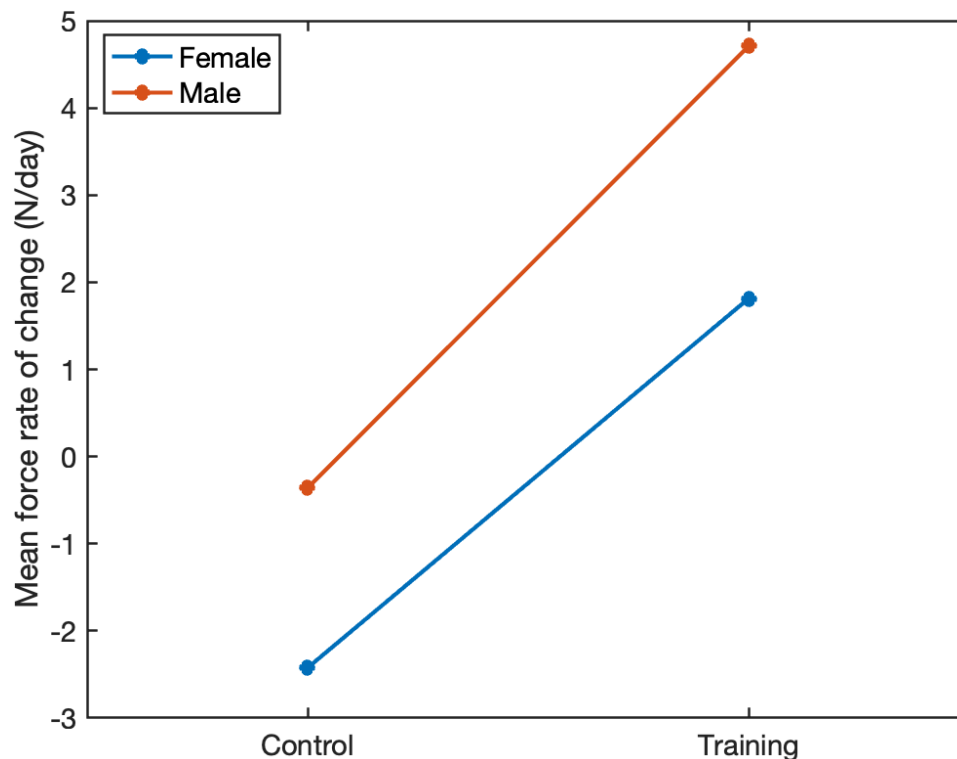


Figure 8: Interaction plot of mean force trajectory. Both males and females had higher rates of improvement with training, and the slope (effect of training) appears the same for both sexes.

E. Endurance (%MVC)

No significant effects were found for mean %MVC rate of change. The treatment effect was not significant ($p = 0.78$), nor were sex ($p = 0.423$) or the interaction ($p = 0.437$), with a

treatment 95% confidence interval of $[-0.59\%, 0.84\%]$ per day. This outcome is consistent with the theoretical expectation that endurance adaptations require longer training durations to become detectable. While some trained participants increased in absolute force, their fatigue profiles over the 60-second trial did not improve proportionally within the two-week window. The near-zero confidence interval width relative to the other metrics suggests that %MVC was the most stable measure across the study, though this stability reflects an absence of change.

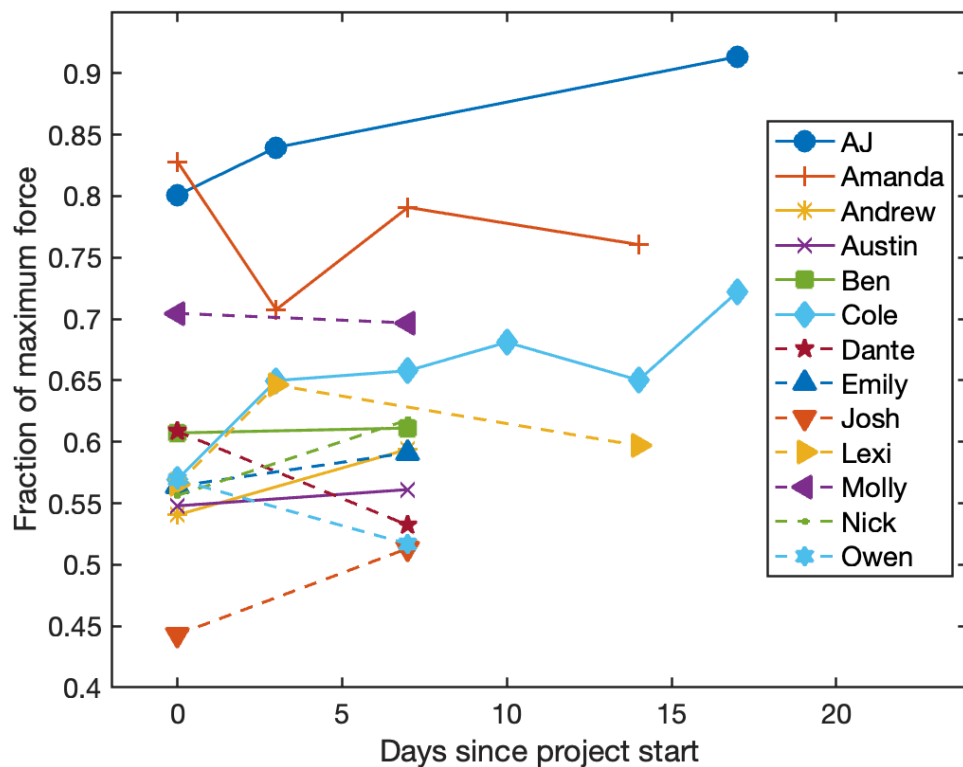


Figure 9: Endurance (normalized mean force) in a sustained effort trial plotted over the course of the project for each participant. The training group consists of AJ, Amanda, Cole, and Lexi.

F. Limitations

Several factors limited the conclusions that can be drawn from this study. The trained group was reduced to four participants following two withdrawals before study completion, which substantially increased variance and widened confidence intervals across all outcomes. One of the three planned control group collection sessions was not obtained due to a lab scheduling conflict, though this is not expected to meaningfully affect the control results given the expectation of negligible change over a short period. Adherence to the daily training protocol relied on self-reporting and could not be independently verified. Resistance on the grip trainer was also set by a fixed difficulty level rather than calibrated to each participant's individual MVC, meaning relative training load was not consistent across participants. These factors collectively contributed to high variance in the outcome measures and restricted the generalizability of the findings.

V. CONCLUSION

The variance, primarily due to low sample size, prevents a solid conclusion from being made of this training program increasing hand grip strength or endurance in a two week period. However, the ANOVA indicated that the training program had a statistically significant effect on average force exerted by each participant with a p value of 0.0277. This shows that the participants that underwent the training program increased their grip strength faster than those who didn't. Male and female subjects did not however show any statistical difference in the rate in which their maximum force or fatigue resistance increased. This is indicated by the ANOVA reporting no interaction between training and sex. A possible explanation for the increases in non-training participants is small increases in muscle or changes in neurological fatigue factors

between the tests, from the exertion of the previous test. Trends in the interaction plots and participant data showed that there are promising trends. But the variance is too high, making the results statistically insignificant. However, these trends could justify further studies with more training subjects.

The main findings of the study include that males have a higher average maximum force than females, but also that all participants had a lower maximum force than the population average. An observation worth noting is that the direction that the hand dynamometer faced made a sizable difference in the force readings, which is why we ended up standardizing the hand dynamometer direction for all participants to ensure comparable results. The device is also an awkward shape, and participants reported feeling discomfort and pain while squeezing it with their maximum effort. These factors may have contributed to the reading being lower than the population average, but the device itself may have had a calibration issue we were unaware of. However, since all participants used the same device, the trends we are reporting on should still be valid.

Further research into this question would be warranted by the trends we have seen. To improve on this study in the future, an increase in the participant and control group would be the most meaningful change, but also refining the training protocol to ensure more consistency among subjects would be beneficial. Another possible procedure could be training one hand and not the other and measuring both, or looking at how hand length might interact with force. Furthermore, looking deeper into Rohmert's Law and its effect on endurance might imply there is no way to increase your endurance without increasing your maximum grip force, and seeing how this fits with our results.

VI. REFERENCES

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VII. APPENDIX

Team Member Contributions

Cole Rinehart: Main contributor to analysis and results. Did a huge amount of the data processing, acted and helped produce the project video.

Amanda Stevens: Conclusion, assisted in writing of introduction, and methods, and wrote conclusion. Made figures, proofread, directed and edited project video.

Alexis “Lexi” Miller: Introduction, abstract, general assistance of project (data collection, participant coordination, etc.)

Anthony “AJ” Javier: Wrote methods / procedures, general assistance with data collection.

MATLAB code

```

%% import data
% forcing sorting data alphabetically,
% which conveniently puts trials in correct order for each participant.
% MATLAB should do this automatically, but just in case.
files = dir("data/*.csv");
[~, fileorder] = sort({files.name});
files = files(fileorder);
data(length(files)) =
struct('participant', "", 'time', [], 'force', [], 'maxForce', [], 'date', "", 'trial', []
, 'hand', "");

for i=1:length(files)
    filename = string(files(i).name);
    filepath = fullfile("data", filename);
    metadata = split(erase(filename, '.csv'), '_');

    dt = 0.1; % mean(diff(values(:,1)));
    time_keep = 55; % how many seconds to keep after peak force reached
    values = readmatrix(filepath); % recorded data
    [~, cutoff] = max(values(1:5/dt, 2)); % maximum reached in 5s

    % trimming data points before first peak and more than 55s after peak,
    % centering peak at t = 0;
    data(i).time = values(cutoff:cutoff+time_keep/dt, 1) ...
        - values(cutoff, 1);
    data(i).force = values(cutoff:cutoff+time_keep/dt, 2);
    data(i).maxForce = max(values(:, 2));
    data(i).participant = string(metadata(1));
    data(i).date = datetime(metadata(2), 'inputformat', 'yyyy-MM-dd');
    data(i).trial = str2double(metadata(3));
    if length(metadata) > 3
        data(i).hand = metadata(4);
    else
        data(i).hand = "R";
    end
end

%clear filename filepath files i metadata values

%% plot of everybody's data, just to make sure it works
figure()
hold on
for i=1:length(data)
    plot(data(i).time, data(i).force, 'DisplayName', data(i).participant)
end

xlim([0 55])
xlabel('Time (s)')

```

```

ylabel('Force (N)')

set(gca,'fontsize',14,'linewidth',1.2,'box','on')
%set(gcf,'position',[10 10 600 300])
exportgraphics(gca,'figures/example0.png')

% example plot
figure()
plot(data(8).time,data(8).force,'LineWidth',2)

xlabel('Time (s)')
ylabel('Force (N)')

set(gca,'fontsize',14,'linewidth',1.2,'box','on')
%set(gcf,'position',[10 10 600 300])
exportgraphics(gca,'figures/example1.png')

%% max force leaderboard
% absolute numbers
leaderboard = table([data.maxForce],[data.participant],[data.date], ...
    'VariableNames',{'Force','Participant','Date'});
leaderboard = sortrows(leaderboard,'Force','descend');
writetable(leaderboard,'leaderboard.xlsx');

%% Analysis of maximum force
% there are multiple options for analyzing change in maximum force:
% 1. look at each person's absolute max (the highest they ever got) and
%    compare to baseline
% 2. look at final max (the maximum of each person's latest trial) and
%    compare to baseline
% 3. look at some projected maximum and compare to baseline?
participantNames = unique([data.participant]);
trt = ["AJ","Amanda","Cole","Lexi"];
female = ["Amanda","Emily","Gilie","Lexi","Molly"];
temp(length(participantNames)) = struct('trialMaximums',[], ...
    'trialDates',[],'trialDays',[],'numTrials',[],'baseline',[], ...
    'absoluteMax',[],'finalValue',[],'trt',[],'sex',[],'fit',[], ...
    'ROCmag',[],'ROCpct',[],'trialTime',[],'trialForce',[], ...
    'AUC',[],'AUCnorm',[]);

for i = 1:length(participantNames)
    temp(i).trialMaximums = [data([data.participant] ==
participantNames(i)).maxForce];
    temp(i).trialDates = [data([data.participant] ==
participantNames(i)).date];
    temp(i).trialDays = days(temp(i).trialDates - min(temp(i).trialDates));
    temp(i).numTrials = length(temp(i).trialDates);
    temp(i).baseline = temp(i).trialMaximums(1);
    temp(i).absoluteMax = max(temp(i).trialMaximums);

```

```

temp(i).finalValue = temp(i).trialMaximums(end);

if ismember(participantNames(i),trt)
    temp(i).trt = 1==1;
else
    temp(i).trt = 1==0;
end

if ismember(participantNames(i),female)
    temp(i).sex = 1==1;
else
    temp(i).sex = 1==0;
end
end

% removing participants with only 1 observation
index = [temp.numTrials] > 1;
participant = temp(index);
participantNames = participantNames(index);

% calculating some sample size variables
n = length(participantNames);
n_trt = length(trt);
n_ctrl = n - n_trt;
n_female = length(female);
n_male = n - n_female;

% and sample means (baseline/first measurement)
sex = [participant.sex];
trt = [participant.trt];
female_trt = sex & trt;
male_trt = ~sex & trt;
female_ctrl = sex & ~trt;
male_ctrl = ~sex & ~trt;

baseline = [participant.baseline];
baseline_mean = mean(baseline);

baseline_female_trt = mean(baseline(female_trt));
baseline_male_trt = mean(baseline(male_trt));
baseline_female_ctrl = mean(baseline(female_ctrl));
baseline_male_ctrl = mean(baseline(male_ctrl));

baseline_female = mean(baseline(sex));
baseline_male = mean(baseline(~sex));

baseline_trt = mean(baseline(trt));
baseline_ctrl = mean(baseline(~trt));

```

```

[~,~,CI_female_trt] = ttest(baseline(female_trt));
[~,~,CI_male_trt] = ttest(baseline(male_trt));
[~,~,CI_female_ctrl] = ttest(baseline(female_ctrl));
[~,~,CI_male_ctrl] = ttest(baseline(male_ctrl));

[~, p_sex_baseline, CI_sex_baseline] = ttest2(baseline(sex), baseline(~sex),
'Vartype','unequal');
[~, p_trt_baseline, CI_trt_baseline] = ttest2(baseline(trt), baseline(~trt),
'Vartype','unequal');
% sex affects baseline strength, treatment group does not

% estimating a rate of change in maximum force for each participant
mdl =@(b,x) b(1).*x + b(2);
for i = 1:n
    fit = polyfit(participant(i).trialDays,participant(i).trialMaximums,1);
    participant(i).linreg = fit;
    participant(i).ROCmag = fit(1);
    participant(i).ROCpct = fit(1)./participant(i).baseline*100;
end

ROCmag = [participant.ROCmag]';
ROCpct = [participant.ROCpct]';

% Two-way ANOVA (using anovan because of unbalanced dataset)
sexLabel = strings(n,1);
sexLabel(sex'==1) = "Female";
sexLabel(sex'==0) = "Male";

trtLabel = strings(n,1);
trtLabel(trt'==1) = "Training";
trtLabel(trt'==0) = "Control";

[p1,tbl1,stats1] = anovan(ROCmag, {sexLabel, trtLabel}, ...
    'model','interaction', ...
    'varnames', {'Sex','Training'});
%writetable(tbl1,'figures\')

[p2,tbl2,stats2] = anovan(ROCpct, {sexLabel, trtLabel}, ...
    'model','interaction', ...
    'varnames', {'Sex','Training'});

% interesting result - all p values decreased a lot when talking about rate
% of change as "% of baseline per day" instead of just "force per day".
% This makes sense to me because normalizing by baseline strength basically
% eliminates some of the random variation associated with baseline strength

% Confidence Intervals for difference of means (male/female and
training/control)
% - 95% CI = (xbar-ybar) ± t*()

```

```

[~, p_sex_ROCpct, CI_sex_ROCpct] = ttest2(ROCpct(sex), ROCpct(~sex),
'Vartype','unequal');
[~, p_trt_ROCpct, CI_trt_ROCpct] = ttest2(ROCpct(trt), ROCpct(~trt),
'Vartype','unequal');
% neither affects strength change over time, slight upward shift in
% difference of sample means for treatment supports anecdotal data, but the
% change is not statistically significant as the 95% CI still crosses 0.

%% Figures / Visualization for maximums
figure()
f = boxplot(baseline,sex);

xticklabels(["Male","Female"])
ylabel("Baseline Hand Grip Strength (N)")

set(findobj(gca,'Type','Line'),'LineWidth',2)
set(gca,'fontsize',14,'linewidth',1,'box','on')
exportgraphics(gcf,'figures/baseline_boxplot.png')

% plotting maximums over time
markers =
["o","+", "*", "x", "square", "diamond", "pentagram", "^", "v", ">", "<", ".", "hexagram"]
;
colors = lines(n);
styles = ["-", "--", "-."];
figure()
hold on
for i = 1:n
    values = participant(i).trialMaximums;
    [uniqueDays, ~, idx] = unique(participant(i).trialDays);
    meanValues = accumarray(idx, values, [], @mean);

    plot(uniqueDays, ...
        meanValues, ...
        'Color',colors(i,:), ...
        'LineStyle', styles(floor(i/7)+1), ...
        'LineWidth',1.5, ...
        'Marker',markers(i), ...
        'MarkerSize',10, ...
        'MarkerFaceColor',colors(i,:), ...
        'DisplayName',participantNames(i))
end

axis([-2 24 120 520])
legend('Location','e','FontSize',14)
xlabel('Days since project start')
ylabel('Maximum force (N)')

set(gca,'fontsize',14,'linewidth',1.2,'box','on')

```

```

exportgraphics(gcf,'figures/max_vs_time.png')

% interaction plot
meanROC_female_trt = mean(ROCpct(female_trt));
meanROC_male_trt = mean(ROCpct(male_trt));
meanROC_female_ctrl = mean(ROCpct(female_ctrl));
meanROC_male_ctrl = mean(ROCpct(male_ctrl));

figure()
plot([1 2],[meanROC_female_ctrl meanROC_female_trt], ...
     'LineWidth',2, ...
     'Marker','o', ...
     'MarkerFaceColor',colors(1,:), ...
     'DisplayName','Female')
hold on
plot([1 2],[meanROC_male_ctrl meanROC_male_trt], ...
     'LineWidth',2, ...
     'Marker','o', ...
     'MarkerFaceColor',colors(2,:), ...
     'DisplayName','Male')

xlim([0.5 2.5])
xticks([1 2])
xticklabels(["Control","Training"])
ylabel('Strength increase (% of baseline per day)')
legend('Location','nw','FontSize',14)

set(gca,'fontsize',14,'linewidth',1.2,'box','on')
exportgraphics(gcf,'figures/strength_interactionplot.png')

%% Analyzing Endurance
% define an area-based metric "sustained performance capacity"
% basically just average output as fraction of max force
for i = 1:n
    participant(i).trialTime = [data([data.participant] ==
participantNames(i)).time];
    participant(i).trialForce = [data([data.participant] ==
participantNames(i)).force];

    AUC = zeros(1,participant(i).numTrials);
    AUCnorm = AUC;
    slope = AUC;
    for j = 1:participant(i).numTrials
        time = participant(i).trialTime(:,j);
        force = participant(i).trialForce(:,j);
        AUC(j) = trapz(time,force); % area under curve
        AUCnorm(j) = AUC(j)/max(time)/max(force);
        fit = polyfit(time,force,1);
        slope(j) = fit(1);
    end
end

```

```

end
participant(i).trialAUC = AUC;
participant(i).trialAUCnorm = AUCnorm;
participant(i).trialSlope = slope;

participant(i).AUCfit =
polyfit(participant(i).trialDays,participant(i).trialAUC/time_keep,1);
participant(i).AUCnormfit =
polyfit(participant(i).trialDays,participant(i).trialAUCnorm,1);
participant(i).trialSlopefit =
polyfit(participant(i).trialDays,participant(i).trialSlope,1);
participant(i).ROCmean = participant(i).AUCfit(1);
participant(i).ROCenduro = participant(i).AUCnormfit(1);
participant(i).ROCslope = participant(i).trialSlopefit(1);
end

% ANOVA
ROCmean = [participant.ROCmean]';
ROCenduro = [participant.ROCenduro]';

[p3,tbl3,stats3] = anovan(ROCmean, {sexLabel, trtLabel}, ...
    'model','interaction', ...
    'varnames', {'Sex','Training'});

[p4,tbl4,stats4] = anovan(ROCenduro, {sexLabel, trtLabel}, ...
    'model','interaction', ...
    'varnames', {'Sex','Training'});

% as expected, lowest p value is for mean increasing with training but will
% have to construct confidence intervals to truly compare

[~, p_sex_ROCmean, CI_sex_ROCmean] = ttest2(ROCmean(sex), ROCmean(~sex),
    'Vartype','unequal');
[~, p_trt_ROCmean, CI_trt_ROCmean] = ttest2(ROCmean(trt), ROCmean(~trt),
    'Vartype','unequal');
[~, p_sex_ROCenduro, CI_sex_ROCenduro] = ttest2(ROCenduro(sex),
    ROCenduro(~sex), 'Vartype','unequal');
[~, p_trt_ROCenduro, CI_trt_ROCenduro] = ttest2(ROCenduro(trt),
    ROCenduro(~trt), 'Vartype','unequal');
% all cross 0, most effect seen in ROCmean vs treatment

%% Endurance plots
% training group may see increase in AUC, but AUCnorm should be flat
% mean
figure()
hold on
for i = 1:n
    values = participant(i).trialAUC/time_keep; % mean force exerted
    [uniqueDays, ~, idx] = unique(participant(i).trialDays);
    meanValues = accumarray(idx, values, [], @mean);

```

```

plot(uniqueDays, ...
     meanValues, ...
     'Color', colors(i,:), ...
     'LineStyle', styles(floor(i/7)+1), ...
     'LineWidth', 1.5, ...
     'Marker', markers(i), ...
     'MarkerSize', 10, ...
     'MarkerFaceColor', colors(i,:), ...
     'DisplayName', participantNames(i))
end

axis([-2 21 80 380])
legend('Location', 'se', 'FontSize', 14)
xlabel('Days since project start')
ylabel('Mean force (N)')

set(gca, 'fontsize', 14, 'linewidth', 1.2, 'box', 'on')
exportgraphics(gcf, 'figures/mean_vs_time.png')

% endurance metric
figure()
hold on
for i = 1:n
    values = participant(i).trialAUCnorm;
    [uniqueDays, ~, idx] = unique(participant(i).trialDays);
    meanValues = accumarray(idx, values, [], @mean);

    plot(uniqueDays, ...
         meanValues, ...
         'Color', colors(i,:), ...
         'LineStyle', styles(floor(i/7)+1), ...
         'LineWidth', 1.5, ...
         'Marker', markers(i), ...
         'MarkerSize', 10, ...
         'MarkerFaceColor', colors(i,:), ...
         'DisplayName', participantNames(i))
end

axis([-2 24 0.4 .95])
legend('Location', 'e', 'FontSize', 14)
xlabel('Days since project start')
ylabel('Fraction of maximum force')

set(gca, 'fontsize', 14, 'linewidth', 1.2, 'box', 'on')
exportgraphics(gcf, 'figures/endurance_metric_vs_time.png')

% slope
figure()

```

```

hold on
for i = 1:n
    values = participant(i).trialSlope;
    [uniqueDays, ~, idx] = unique(participant(i).trialDays);
    meanValues = accumarray(idx, values, [], @mean);

    plot(uniqueDays, ...
        meanValues, ...
        'Color', colors(i,:), ...
        'LineStyle', styles(floor(i/7)+1), ...
        'LineWidth', 1.5, ...
        'Marker', markers(i), ...
        'MarkerSize', 10, ...
        'MarkerFaceColor', colors(i,:), ...
        'DisplayName', participantNames(i))
end

axis([-2 23 -4.9 0.4])
legend('Location', 'e', 'FontSize', 14)
xlabel('Days since project start')
ylabel('Slope of dynamometer measurement')

set(gca, 'fontsize', 14, 'linewidth', 1.2, 'box', 'on')
exportgraphics(gcf, 'figures/slope_vs_time.png')

% interaction plot (mean)
meanROCmean_female_trt = mean(ROCmean(female_trt));
meanROCmean_male_trt = mean(ROCmean(male_trt));
meanROCmean_female_ctrl = mean(ROCmean(female_ctrl));
meanROCmean_male_ctrl = mean(ROCmean(male_ctrl));

figure()
plot([1 2], [meanROCmean_female_ctrl meanROCmean_female_trt], ...
    'LineWidth', 2, ...
    'Marker', 'o', ...
    'MarkerFaceColor', colors(1,:), ...
    'DisplayName', 'Female')
hold on
plot([1 2], [meanROCmean_male_ctrl meanROCmean_male_trt], ...
    'LineWidth', 2, ...
    'Marker', 'o', ...
    'MarkerFaceColor', colors(2,:), ...
    'DisplayName', 'Male')

xlim([0.5 2.5])
xticks([1 2])
xticklabels(['Control', 'Training'])
ylabel('Mean force rate of change (N/day)')
legend('Location', 'nw', 'FontSize', 14)

```

```

set(gca,'fontsize',14,'linewidth',1.2,'box','on')
exportgraphics(gcf,'figures/mean_strength_interactionplot.png')

% interaction plot (endurance)
meanROCenduro_female_trt = mean(ROCenduro(female_trt));
meanROCenduro_male_trt = mean(ROCenduro(male_trt));
meanROCenduro_female_ctrl = mean(ROCenduro(female_ctrl));
meanROCenduro_male_ctrl = mean(ROCenduro(male_ctrl));

figure()
plot([1 2],[meanROCenduro_female_ctrl meanROCenduro_female_trt]*100, ...
     'LineWidth',2, ...
     'Marker','o', ...
     'MarkerFaceColor',colors(1,:), ...
     'DisplayName','Female')
hold on
plot([1 2],[meanROCenduro_male_ctrl meanROCenduro_male_trt]*100, ...
     'LineWidth',2, ...
     'Marker','o', ...
     'MarkerFaceColor',colors(2,:), ...
     'DisplayName','Male')

axis([0.5 2.5 -.2 .7])
xticks([1 2])
xticklabels(["Control","Training"])
ylabel('Endurance rate of change (%max force/day)')
legend('Location','nw','FontSize',14)

set(gca,'fontsize',14,'linewidth',1.2,'box','on')
exportgraphics(gcf,'figures/enduro_interactionplot.png')

```