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PLAB 2: Dive Response

Abstract:

Dive response is a natural mechanism of the body in response to being submerged in water. The autonomic response consists of rapidly induced bradycardia as well as vasoconstriction of the peripheral vessels, both of which aid in the preservation of body heat and oxygen. In this lab the common effects of dive response were monitored under simulated dive conditions, breath-holding conditions and normal breathing conditions. Heart rate and pulse amplitude were monitored using a finger pulse transducer and changes in peripheral circulation were calculated using a sphygmomanometer and a respiratory belt. It was found that both heart rate and peripheral circulation were reduced in the breath holding and even more so in the dive conditions than under normal breathing.

Results

The data obtained in this lab was very inconsistent. Neither the TA nor the lab technician was cable of solving some of the issues, and attributed them to faulty equipment. To remain consistent with the different plots, data from a peer group (Citation #1) was borrowed in making the majority of the results. The calibration curve was formed from personal data; however the plots for problem 1-4 were derived from analyzing cleaner and less noisy borrowed data of the same experiments.

Problem 1:

Figure 1 shows a plot of heart rate vs time for exercises 1 and 2 on the same graph. The plots are aligned such that the initiation of the dive in experiment 1 occurs at the same time (15seconds) as the initiation of the subject holding their breath, and the release of both the dive and the holding of the patient's breath are aligned at 45 seconds. The experiment ends at 70seconds despite some additional recording. These markers separate 3 phases: rest/normal, dive/holding breath, and the recovery.

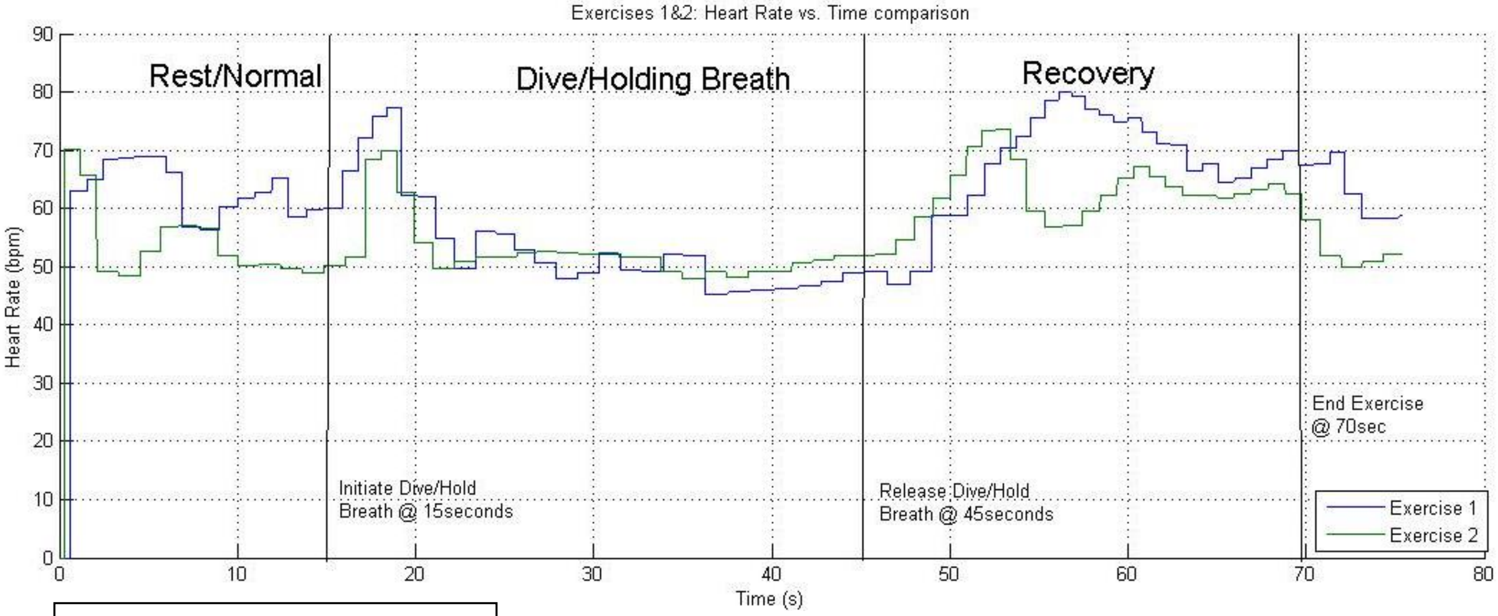


Figure 1: Heart Rate vs. Time compared for exercises 1 and 2

Problem 2:

Figure 2 shows plots of pulse amplitude vs time for exercises 1 and 2. The plots are aligned in the same exact manner as Figure 1, and the onset of events is identical. (The data is from the same time trials as Figure 1)

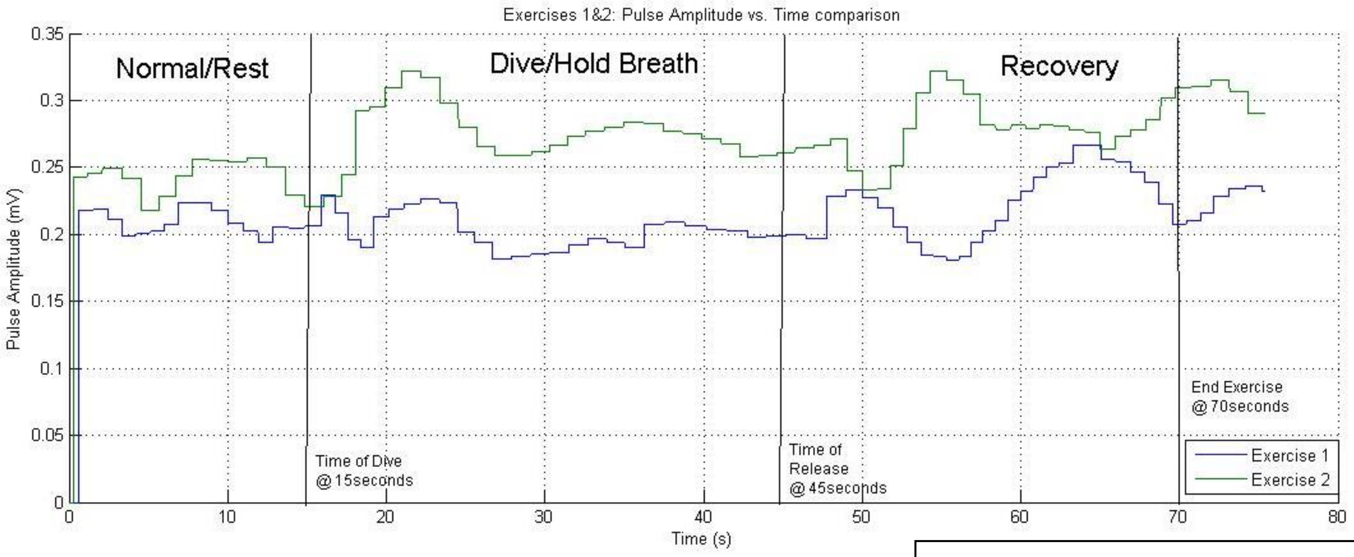


Figure 2: Pulse Amplitude vs. Time compared for exercises 1 and 2

Problem 3:

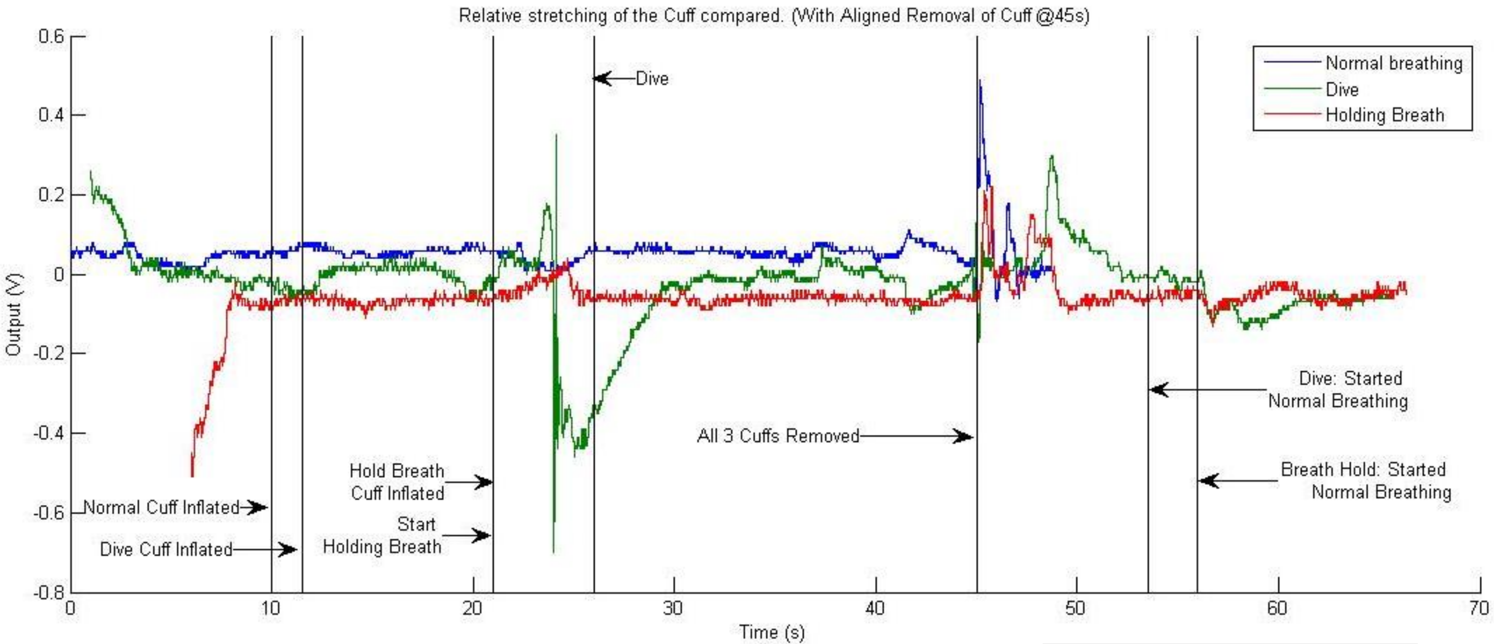
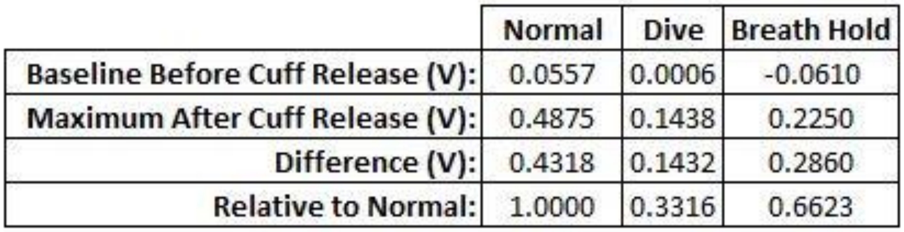


Figure 3: Stretching of cuff compared

Problem 4:

Table 1 shows the changes in peripheral blood volume as represented by changes in ampltude when the cuff is removed. Because this is not a volume measurement (it is a voltage change recorded from the respiratory belt) the measurements are only relative. Thus the valuable information in Table 1 is the last row "Relative to Normal, " which inidcates the *relative* change in peripheral blood volume.



	Normal	Dive	Breath Hold
Baseline Before Cuff Release (V):	0.0557	0.0006	-0.0610
Maximum After Cuff Release (V):	0.4875	0.1438	0.2250
Difference (V):	0.4318	0.1432	0.2860
Relative to Normal:	1.0000	0.3316	0.6623

Table 1: Relative Changes in Peripheral Blood Volume

Problem 5:

In order to convery the relative ampltiude recordings to useful and tangible values a calibration curve was created. The output equation allows an input voltage to be converted to an output of physical stretch length (in mm). The orientation of the dependant and independent axis were chosen here to give a corresponding input output equation that would be directly useful without solving for input given an output.

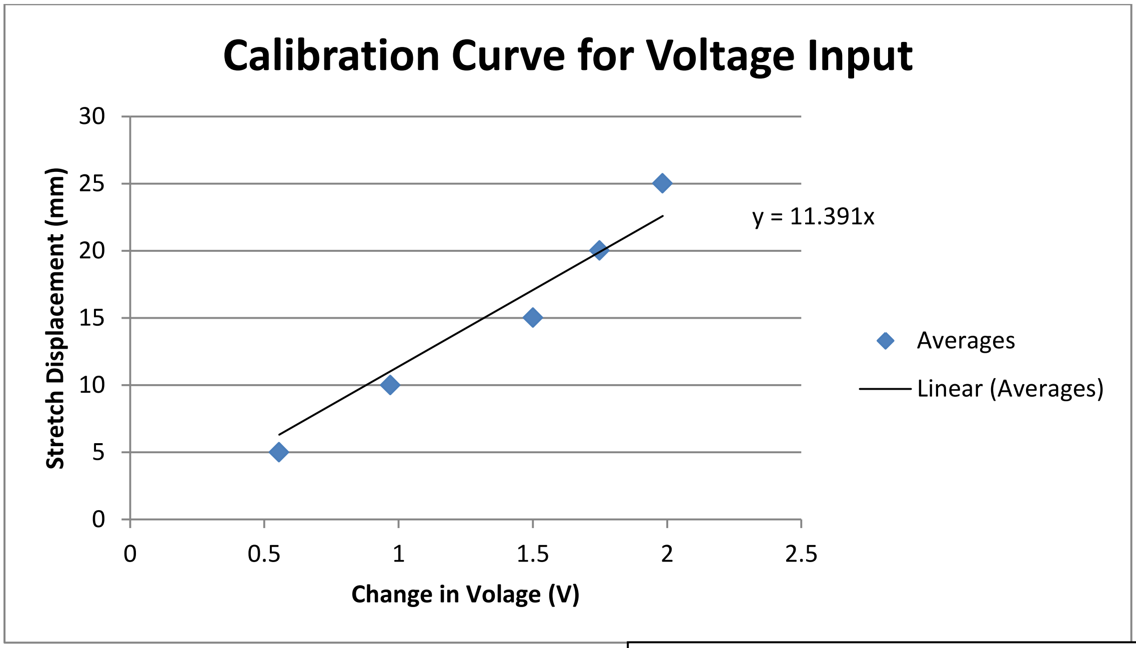


Figure 4: Calibration Curve for voltage to stretch circumference change

Discussion:

Problem 2: Looking at Figure 1 (comparison of heart rates for experiments 1 &2), there is a very similar trend but an important distinction between the two sets of data. First, it is important to note that this subject was a trained athlete and had an extremely low but healthy resting heart rate. During the rest/normal phase where the subject had not yet initiated a dive or started holding his breath, the dive data shows a slightly higher heart rate. Considering the actual conditions of these two sets of data are identical for the first phase, the slight deviation is likely due to psychological effect of facing a cold basin of water early in the morning. Once the subject initiates the dive, the heart rate suddenly increases (most likely from shock) and then just as quickly decreases to lower than it was at its resting value. In other words the dive induces a slight shock and then quickly induces mild bradycardia. The demonstration might have been even clearer on a subject without such a low resting heart rate. In the case of exercise 2 (breath hold), the same initial shock hits after initiation of the restriction, but the heart rate simply returns to a value nearer to baseline. This is the most important distinction and results from the difference between the conditions of the two exercises. In exercise 1 (the dive), the body thinks it is entering water, and because of the extremely efficient conduction of heat that occurs between water and the body paired with the inability to obtain oxygen while diving, the body implements a natural mechanism of survival. It decreases heart rate and constricts blood vessels of the periphery to keep flow to extremities at a minimum. This accomplishes two things. It conserves oxygen and keeps the heat centered and better maintained in the torso. Two features crucial to survival during submersion. When the patient holds their breath in experiment 2, no such mechanism for heat conservation is triggered. After release of the dive/holding breath, the subject undergoes a period of recovery where there exists an incline in heart rate to a peak higher than rest and then a return to resting rate. Speculation on the cause of the initial incline includes the removal of any survival mechanism upon the release, but also a possible overcompensation effect from the intake of more than normal levels of oxygen. If the subject begins breathing after holding their breath, even when trying to do so at a normal resting rate, will most likely intake more than normal quantities of oxygen by breathing too hard. The heart may compensate by increasing heart rate. The peak of heart rate during recovery is higher in the dive exercise than in exercise 2 because of the attempt to return blood to extremities than may have been restricted and because the overcompensation breathing is much higher after “coming up for air” as opposed to simply allowing one’s self to breath.

The pulse amplitude graphs provide a lot less information unfortunately. They indicate less intrinsically, but also are prone to inaccuracy by design of the device used to record them. The device used to record the amplitude response was a finger clamp, and any minor bumps distorted the data. This could account for some of the differences in transition from rest to action between exercises 1 and 2. In exercise 1, the pulse amplitude quickly increases and then decreases upon the dive (indicating vasoconstriction congruent with the previously mentioned survival mechanism), but in exercise 2 when the subject holds his breath the pulse amplitude increases for longer before decreasing. The exact translation of the pulse amplitude is a bit vague. A smaller amplitude indicates vasoconstriction (smaller diameter vessel), but it could theoretically indicate blood pressure which would make some sense in this setting. The following is speculation. If the heart rate decreases upon diving yet the organs still require the same amount of oxygen, then the oxygen must be supplied somehow and the answer might be increased blood pressure. Upon the onset of the dive, the pressure increases to compensate for bradycardia. This inverse proportionality relationship between pressure and heart rate to maintain adequate oxygen to organs is evident most clearly in the recovery phase where the recovery phase in figure 2 (pulse amplitude) directly but inversely mirrors the recovery of figure 1 (heart rate). This is pure speculation however. It is safe to assume vasoconstriction is clearly indicated by the pulse amplitude decreasing and dilation by the pulse amplitude increasing.

Problem 3: A few environmental factors were mentioned previously, but the main factor is the presence of cold in the dive response and not in the breath-holding response. The temperature factor dramatically affects response as does the direct application of water to the face where receptors for survival mechanisms are located.

Problem 4&5: Looking at table 1 for cuff removal stretch amplitude, the amplitude in the dive scenario was ~ 30% of the control amplitude during normal breathing and the amplitude of the breath-holding scenario was ~70% that of the control with normal breathing. This means that when the cuff was removed in oxygen deprived scenarios, the return to normal volume was ~30% less for breath-holding subject and ~70% less for a diving subject. What this indicates is less peripheral circulation. If blood is not being pushed as hard to the leg (representing the periphery), then the volume will not return to normal as quickly. Although a large difference was present between the dive and the breath-holding, both showed notable deviation relative to control. This hints that although the dive clearly resulted in more decreased peripheral circulation, that change in peripheral circulation could be induced by non-diving oxygen deprivation such as during a breath-hold. The fact that the results for the breath-holding were weaker than that of the dive is congruent with the previously mentioned mechanisms of dive response. If the dive response triggers vasoconstriction to maintain body heat and oxygen, then a dramatic change in peripheral circulation would be expected specifically as a result of the dive and its associated conditions. What is unclear however, is the origin of the decreased peripheral circulation during breath-holding. The results are not definitive by any means, but little evidence or alternate research could be found to support the findings.

Problem 6: Although already mentioned, the main advantages of a dive response consisting of bradycardia and the decrease in peripheral circulation (by vasoconstriction) would be maintenance/preservation of body heat and oxygen. If the body keeps blood in the torso, most of the organs remain supplied and the heat loss is minimal (maximum volume to minimal surface area). Additionally removing oxygen supply to the periphery composed of a lot of skeletal muscle keeps from wasting oxygen on unnecessary recipients. However, during a real dive, where movement is key to getting out of the water or moving around in water, circulation can be key. Additionally maintenance of blood flow to the brain is very important. If a “dive” refers to an actual deep dive, the “bends” caused by rapid changes in pressure must be taken into account and depth changes must be made slowly.

Problem 7: Using a very crude estimate of the subject's leg as a cylinder, and assuming the circumference increases by the same amount over the entire length of the leg, physical values for changes in blood volume were calculated. Using the following code:

```
close all; clear all; clc;
amp_change = [0.4318,0.1432,0.2860];  %normal,dive and then breath-holding
circumference_change = 11.391*amp_change/10;
resting_leg_circumference = 35;
resting_leg_radius = resting_leg_circumference/(2*pi); %cm
 for i = 1:length(amp_change)
    shrunken_radius(i) = resting_leg_radius-circumference_change(i)/(2*pi);

end
 length_cylinder = 60; %cm
%assume cylinder
for i = 1:length(amp_change)
    change_vol(i) = length_cylinder*pi*(resting_leg_radius^2-shrunken_radius(i)^2);
end
 normal_change_in_ml = change_vol(1)
dive_change_in_ml = change_vol(2)
breath_change_in_ml = change_vol(3)
 for i = 1:length(amp_change)
    change_relative_to_normal(i) = change_vol(i)/change_vol(1);
end
```

the values for changes in blood volume were found to be as follows.

The change in blood volume 162.3ml under normal breathing, 54.39ml under dive conditions and 108.4ml under breath-holding conditions. This translates to the exact same relative (to normal) values of 1, 0.3316, 0.6623 (from Table 1) respectively which is expected given the use of the formula from the calibration curve. The volumes represented here are an overestimate because the leg is not a cylinder, nor does its circumference or diameter change in a strictly linear fashion. This estimation is crude, but the relative values are informative.

Discussants:

Paras Vora, Matt Everett, Lauren Bedell

Unofficial Sources:

Data borrowed from Paras Vora, Mathew Everett and Karthik Krishnan

Code:

%For problem 1 and 2 from results

```
close all; clear all; clc;
exercise1_data = load('hr_pa_ex1.txt');
exercise2_data = load('hr_pa_ex2.txt');

exercise1_time = exercise1_data(:,1);
exercise2_time = exercise2_data(:,1);
exercise1_HR = exercise1_data(:,2);
exercise2_HR = exercise2_data(:,2);
exercise1_amp = exercise1_data(:,3);
exercise2_amp = exercise2_data(:,3);

%For exercise 1: dive happened at 15
%For exercise 2: breath holding happened at 15
%recovery starts at 45

%plot amplitude vs. time
figure;hold all;
plot(exercise1_time,exercise1_HR);
plot(exercise2_time,exercise2_HR);
grid on;
title('Exercises 1&2: Heart Rate vs. Time comparison');
xlabel('Time (s)');  ylabel('Heart Rate (bpm)');
legend('Exercise 1','Exercise 2');

%plot amplitude vs. time
figure; hold all;
plot(exercise1_time,exercise1_amp);
plot(exercise2_time,exercise2_amp);
grid on;
title('Exercises 1&2: Pulse Amplitude vs. Time comparison');
xlabel('Time (s)');  ylabel('Pulse Amplitude (mV)');
legend('Exercise 1','Exercise 2');




%This is for Problem 3 from results
%Part 1 2 and 3
%Normal Dive and Breath Hold

%Part 1: Cuff Inflated @ 10                     cuff removed @ 45
%Part 2: Cuff Inflated @ 10.5   dive @ 25       cuff removed @ 44   normal
%breathing @ 52.5
%Part 3: Cuff Inflated @ 15    breath hold @ 15 cuff removed @ 39   normal
%breathing @50

close all; clear all; clc;
exercise3_normal_data = load('exercise3_normal.txt');
```

```
exercise3_dive_data = load('exercise3_dive.txt');
exercise3_breath_data = load('exercise3_breathhold.txt');

normal_time = exercise3_normal_data(:,1)-exercise3_normal_data(1,1);
dive_time = exercise3_dive_data(:,1)-exercise3_dive_data(1,1);
breath_time = exercise3_breath_data(:,1)-exercise3_breath_data(1,1);

normal_strain = exercise3_normal_data(:,2);
dive_strain = exercise3_dive_data(:,2);
breath_strain = exercise3_breath_data(:,2);

figure; hold all;
plot(normal_time,normal_strain);
plot(dive_time+1,dive_strain);
plot(breath_time+6,breath_strain);
title('Relative stretching of the Cuff compared. (With Aligned Removal of
Cuff @45s)');
xlabel('Time (s)');
ylabel('Output (V)');
legend('Normal breathing','Dive','Holding Breath');
%Shifted Graphs: altered times of events
%Part 1: Cuff Inflated @ 10                     cuff removed @ 45
%Part 2: Cuff Inflated @ 11.5   dive @ 26       cuff removed @ 45   normal
%breathing @ 53.5
%Part 3: Cuff Inflated @ 21    breath hold @ 21 cuff removed @ 45   normal
%breathing @56
yL = get(gca,'YLim');
line([10 10],yL,'Color','k');
line([11.5 11.5],yL,'Color','k');
line([21 21],yL,'Color','k');
line([26 26],yL,'Color','k');
line([45 45],yL,'Color','k');
line([53.5 53.5],yL,'Color','k');
line([56 56],yL,'Color','k');
```