"Is there a relationship between inhibiting antagonist muscles and the power output of agonist muscles using Pushups and stretching?"

Introduction and Aim

The aim of this investigation is to find out how much work can be done by the agonist muscles in a certain time period (i.e. *power)* directly after inhibiting antagonist muscles. This is of great interest to me because my personal strength routine involves alternating exercises that use antagonistic muscle pairings and I wanted to see how much of an effect this has. Moreover, this concept is widely used in the fitness world and in physical therapy to help manage injuries.

Most skeletal muscles work in antagonistic pairs – as a muscle contracts (e.g. the biceps brachii in elbow flexion), another relaxes (triceps brachii), allowing movement in opposite directions. However, when agonist muscles move the skeleton in any direction, there is always some contraction of antagonist muscles too in the opposite direction (they are never fully relaxed as some muscle *tone* is always maintained) - thus making movements less efficient. A simple analogy is a 'tug of war' [1] - this investigation explores whether stretching and fatiguing the antagonist muscles can reduce the resistance from antagonist muscles.

Fundamental Background Theory (related to IB topics 8.2 and 11.2)

Muscle contraction relies on chemical energy being converted to mechanical energy. Many skeletal muscles have stored glycogen and ATP. Moreover, during short bouts of intense exercise phosphocreatine reserves can be used to form ATP (the ATP-PC system):

Equation 1: Phosphocreatine + ADP (at rest) ⇌ Creatine + ATP (during intense exercise) [2]

This system is used for 10-15 seconds of intense exercise before (anaerobic) glycolysis is used[3]. After 1-2 minutes more aerobic respiration starts to occur (aided by myoglobin reserves for oxygen and muscular glycogen for substrate). In reality, the body uses a mix of these energy systems during exercise, shown in figure 1. However, under two minutes of intense exercise most contributions arise from the ATP-PC system and glycolysis as they are readily available and don't rely on heart rate to provide oxygen. I predict if antagonist muscles are subjected to intense stretching, local ATP and phosphocreatine reserves will be exhausted, increasing reliance on the slower process of glycolysis, decreasing the antagonist muscle's power. [4]

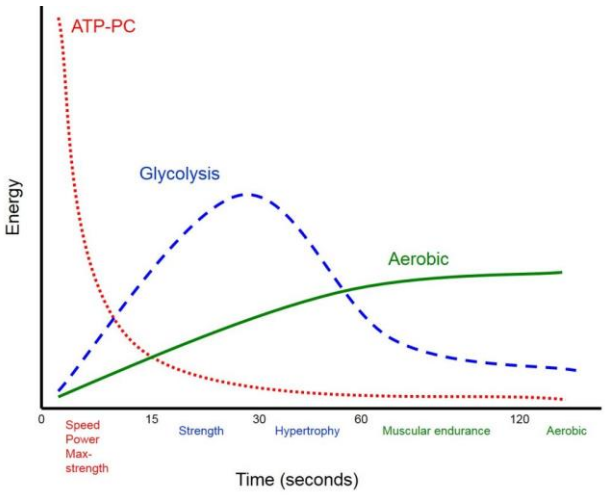


Figure 1 – Energy System Usage during Exercise [4]

[1] Low, S., 2016. *Overcoming Gravity*. pp.14-15.
[2] Phosphagen System | BioNinja. Retrieved [25/8/20], https://ib.bioninja.com.au/higher-level/topic-8-metabolism-cell/untitled/phosphagen-system.html
[3] Creatine Phosphate | ScienceDirect Topics. (2013). Retrieved [25/8/20], https://www.sciencedirect.com/topics/nursing-and-health-professions/creatine-phosphate
[4] *Time Under Tension*| NZIHF Retrieved [25/8/20],https://nzihf.ac.nz/personal-training/time-under-tension/

The inhibition of antagonist muscles during agonistic contraction occurs as follow[5]:

1) Normal muscle contraction is initiated. The CNS sends an action potential down a neuron, causing acetylcholine release at the neuromuscular junction, Ca^{2+} release from sarcoplasmic reticulum, binding of Ca^{2+} ions to troponin, tropomyosin exposure, actin-myosin cross-bridge formation and the "sliding-filament" theory (using ATP)[6].
2) This stretches muscle spindles, which send action potentials via sensory neurons to the spinal cord, where they are received by an inhibitory interneuron.
3) The interneuron inhibits the firing of the (alpha) motor neuron supplying the antagonist muscle, limiting its contraction.

The purpose of this investigation is to see whether techniques that try to fatigue and stretch (static stretching is well known to reduce the power output of muscles[7]) antagonist muscles help reduce the resistance from them in movements powered by agonist muscles, thus increasing how much power the agonists can exert. This leads to the research question**, "Is there a relationship between inhibiting antagonist muscles (via stretching) and the power output of agonist muscles (pushup output in 30s)?",** where stretching time is the independent variable and pushup output is the dependent variable**.** It is unclear whether these techniques work simply by using up fuel sources in the antagonists or if they could make the *neurological process* of antagonist inhibition more efficient.

Equipment and Uncertainties

A stopwatch and another person are needed. Although the stopwatch is likely to be certain to ± 0.005s; human reaction time dictates around a ± 0.2s response time (two people needed) so this is the associated uncertainty with how long participants hold the stretch.
However, the major uncertainty is in the time taken switching *between* stretching and pushups. I estimate this had up to ± 3s uncertainty on pushup durations.

Experimental Methodology

1) Hold the reverse tabletop stretch for $\mathcal{X}$ seconds (0s (control) & 10s,20s,30s,40s,50s,60s) with hands facing towards legs and knees bent 90 degrees to the abdomen (figure 2).
2) After $\mathcal{X}$ seconds (announced by the person with the timer), the participant does as many repetitions of the traditional pushup (shown in figure 3) exercise as possible in 30s.
3) Record how many *complete* pushups (times chest touched floor) were achieved in 30s.
4) Rest for 24 hours to ensure the CNS and muscles can fully recover (see *Variables* section).
5) At the end of the experiment, a questionnaire is taken to yield qualitative results.

[5] Reciprocal Inhibition | ScienceDirect Topics. Retrieved [25/8/20], https://www.sciencedirect.com/topics/veterinary-science-and-veterinary-medicine/reciprocal-inhibition
[6] Muscle Contraction | BioNinja. Retrieved [12/9/20], https://ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/muscle-contraction.html
[7] Gergley, J. (2013). Acute Effect of Passive Static Stretching on Lower-Body Strength in Moderately Trained Men. *Journal Of Strength And Conditioning Research*, *27*(4), 973-977. doi: 10.1519/jsc.0b013e318260b7ce

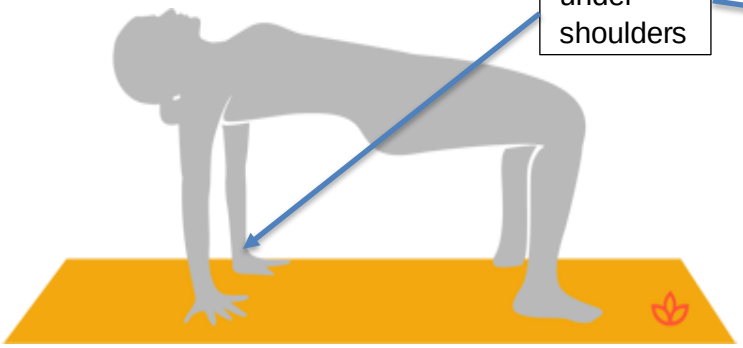


Figure 2 - Reverse Tabletop Stretch [9]

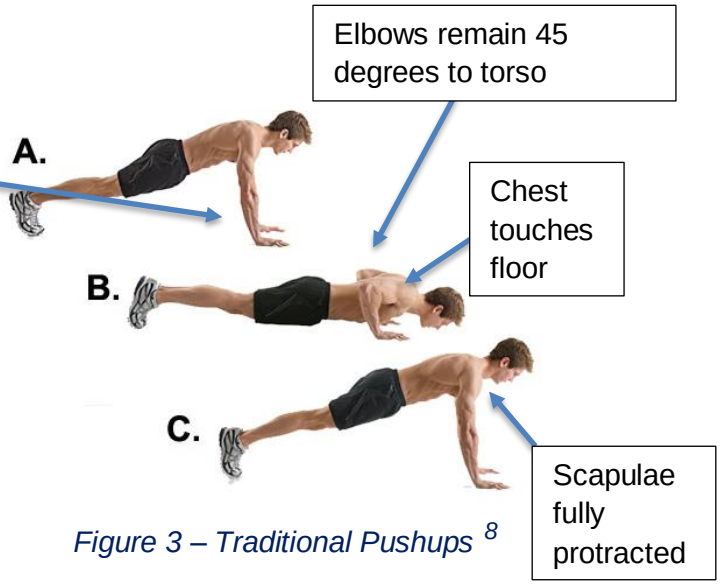


Figure 3 – Traditional Pushups [8]

Pushups and the reverse tabletop stretch were chosen together not only because they were easy to perform with minimal equipment and easy to switch between, but also due to the nature of the muscles utilized. Major agonist muscles during pushups are the pectoralis major, anterior deltoids and triceps brachii. The reverse tabletop position actively stretches the biceps brachii (antagonist to triceps) as the forearms are pronated and engages back muscles like the rhomboids (the antagonists to the pectoralis major) tiring them out.

Risk Assessment

The primary risk/ethical issue to be considered was exercise-onset injury. All participants were familiar with pushups before this experiment, so were sufficiently adapted to the biomechanical challenges. However, although the rest time (24hrs) was probably great enough for muscles to recover, the same cannot be said for tendons and ligaments (these have less blood flow to them so take longer to recover[10]) and risks of tendonitis/ligament damage was considered. I applied the precautionary principle and told the participants that if they ever began to feel pain during the exercise, they would stop the experiment entirely and, if it became worse, to consult a medical professional. This was agreed in a written consent form as an understood risk (in Appendix). There are no environmental concerns with this experiment.

Preliminary Experiment

To decide whether this investigation could produce significant results I performed the test myself with 0,5, 10, 15 & 20 seconds of stretching over 5 days.

[8] Form Thursday – Pushups. Socacize Stars 2014. Retrieved [22/11/20], https://socacizestars.wordpress.com/2014/03/13/form-thursday-push-ups/
[9] *What is Crab Pose?* – Yogapedia 2018.Retrieved [25/8/20], https://www.yogapedia.com/definition/7361/crab-pose
[10] Plenge, L. (2020). *Poor blood supply to tendons means they take longer to repair*. Retrieved [25/8/20], https://www.physiocomestoyou.co.uk/blog/all-you-need-to-know-about-tendons/

	Stretching Time (s)				
	0	5	10	15	20
Number of Pushups in 30s (number)	15	14	14	16	16

Figure 4 – Results of 5-day Preliminary Experiment

Between some 5s increments there was no change in pushup number (see figure 4), so I decided to use 10s increments instead. I also tried holding the stretch for longer than 60 seconds but found it hard to keep a constant body position and maintain the same intensity of stretch on the biceps brachii so set this as a maximum. 30s of pushups was chosen as I was able to do pushups with consistent form. Despite individual differences, I felt the adaptations made were appropriate for the chosen participants.

Controlling the Variables

Before explaining how the independent and control variables were maintained I considered possible confounding variables:

1) People can gain strength between days, increasing the number of pushups done in 30 seconds. Muscular strength is defined as: "*Muscle Cross-sectional Area X Neurological Adaptations*"[11]. To minimise this effect, pushups were done within a short period of time, one week - it is generally accepted that within a week the cross-sectional area of muscles does not significantly increase and as participants were already accustomed to regular pushups (doing them at least twice a week), neurological adaptation was also limited. Strength is not a major confounder.
2) As participants gain flexibility, the effects of stretching diminish over time. Again, it is accepted that this usually only occurs with longer bouts of stretching (above 2 minutes) over a very long period and so is unlikely to change the outcome of my investigation.
3) Age and sex were unlikely to be significant confounding variables as all participants were males between the ages of 16 and 17. Other factors like height, weight and fitness, however, did vary between participants and are therefore recorded below.
4) Increasing mental resilience – some individuals will try harder to maximize the number of pushups (voluntarily or subconsciously). This level of resilience was not assumed to change over this period, but may have changed and, unfortunately, cannot be measured.

[11] Low, S., 2016. *Overcoming Gravity*. pp.14-15.

Figure 5 – Control of Variables and Explanations

Variable and Type	Why must it be controlled?	How was it controlled or monitored?
Stretching Time	This is the independent variable (being changed).	After $\mathcal{X}$ seconds of stretching the person holding the stopwatch announced it and pushups begin.
Duration of time doing pushups (30s)	If participants exceeded or stopped before 30s it would result in less or more pushups than possible in the 30s. It was important that any effects of inhibition were still felt during the time performing pushups, so the time was limited at 30s, even though some participants could've continued.	Person holding timer announces when to start and finish. The major limitation with this method is time being lost when switching between the stretching position and pushups.
Pushup and Stretching Technique (Identical Exercises)	If all participants did different stretches, they may feel different levels of antagonist inhibition; if they were to do a different style of pushups they may have easily got more or less than if they would've done the same pushups as everyone else.	Participants were shown the same video about how to perform traditional pushups/the stretch and assessed to ensure they had similar techniques. Anatomical differences mean techniques are never truly identical, though.
Central Nervous System Fatigue and Tiredness (Motor Unit Use)	The CNS drives skeletal muscles contraction - efficiency in motor unit recruitment depends on factors such as sleep and general stress, as well as if multi-joint movements had been performed earlier. There are no "overarching physiological explanations" but CNS fatigue is thought to occur more when more parts of the brain are overworked without rest and it has a direct impact on power output [12].	Each participant performed the experiment at similar times each day - ensuring each day there had been similar levels of food consumption, sleep and hydration to mimic similar states of CNS fatigue/general tiredness.
Muscular Fatigue and Soreness	This is distinct from tiredness and refers to the level of damage the muscles are in from previous exercise in both the longer term (state of breakdown of myofibrils) or shorter term (metabolites from anaerobic exercise beforehand). Soreness is thought to be caused by microtrauma[13] and can significantly affect the psychological tolerance of pushups - reducing the number of pushups done. New movement patterns can cause soreness[14] and further myofibril breakdown. If participants are already accustomed to exercise intensity/frequency, change in both factors is minimised.	Participants were already accustomed to doing pushups regularly (2+days/wk.) and rested at least 24 hours between experiments. Participants who did other exercise could do so only *after* the experiment each day. If still sore, they skipped a day and performed the experiment 48 hours later to allow full recovery.

[12] Low, S., 2016. *Overcoming Gravity*. pp.14-15.
[13] Lewis, P., Ruby, D., & Bush-Joseph, C. (2012). *Muscle Soreness and Delayed-Onset Muscle Soreness*. *Clinics in Sports Medicine*, *31*(2), 255-262. doi: 10.1016/j.csm.2011.09.009, *Abstract*.

Analysis: Raw Data and Data Processing

Height (cm)	**160-170:** 4	**171-180**: 4	**181-190:** 2
Weight (kg)	**50-60:** 2	**61-70:** 6	**71-80:** 2
Range of Mean Pushups performed weekly before experiment	**5-15:** 5	**16-29:** 4	**29-34:** 1
Did the stretching longer make the Pushups feel easier? (Y/N/Worse)	**Yes:** 4	**No:** 4	**Worse:** 2

Figure 6 – Questionnaire Results for the 10 participants in the experiment

Figure 6 shows the range of participants involved was broad - considering all the participants were aged 17 the variation in heights and weights are not surprising. As aforementioned, all participants were doing pushups before the experiment and were chosen in this way to minimise injury risks. The most interesting aspect of the survey is whether participants *felt* the stretching helped with the pushups - as reflected by some of the results below some did not feel the stretching helped or even worsened their performance. Although this is a qualitative observation, the perception of whether exercises help (i.e. placebos) are incredibly important as they can boost performance even if the stretching did nothing to their muscles! - I did not tell the participants what I expected the trend to be so these are purely their own views.

The raw data for the 10 participants is shown in Figure 7. For each stretching time, I calculated mean and standard deviation values**.**

Example mean calculation (60s stretching) – equation 2:

$$\bar{x} = \frac{\sum(Pushup\ Values)}{Total\ number\ of\ participants} = \frac{\sum(21+27+24+22+16+33+25+7+30+27)}{10} = 23\ (2sf)$$

Example standard deviation calculation (60s stretching) – equation 3:

$$\sigma = \frac{\sum(Individual\ Pushup\ Numbers - Mean)}{Total\ number\ of\ participants} = \frac{\sum(x-\bar{x})^2}{10} = \pm 7\ (1sf)$$

[14] Why do I feel pain after exercise? NHS (2017). Retrieved [25/8/20], https://www.nhs.uk/live-well/exercise/pain-after-exercise/

Figure 7 – Results of how time spent stretching in the tabletop position affects power output, measured by the number of pushups done in 30s directly afterwards

	Number of pushups (done in 30s ± 3)										Calculations	
Time of Stretching in Tabletop Position (s) ±0.2	**Person 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**$\bar{x}$**	**σ**
00.0	16	26	27	25	12	36	22	8	26	26	***22***	***8***
10.0	17	25	20	20	13	34	24	8	24	25	***21***	***7***
20.0	16	26	22	20	15	35	25	7	23	26	***22***	***7***
30.0	16	26	22	24	15	34	25	8	22	27	***22***	***7***
40.0	18	27	24	20	16	30	23	5	27	27	***22***	***7***
50.0	18	24	25	24	17	32	24	8	28	28	***23***	***7***
60.0	21	27	24	22	16	33	25	7	30	27	***23***	***7***

Looking at the raw data as a whole there is no simple linear relationship - for the same participant there were sometimes up to 3 or 4 identical results regardless of stretching times and sometimes an increase in stretching time decreased their pushup numbers, but increased it at other times. Looking at the means of the pushup numbers, any trend is very small and significantly dwarfed by the standard deviations of the sets. However, there does seem to be some positive correlation between stretching time and power output (measured by the number of pushups in 30s after stretching) including and beyond 10s of stretching. This is easier to see in a figure 8, which uses **mean values** and **error bars showing standard deviation** (it is assumed 10 “repeats” for each value of the independent variable is enough data quantity).

[NB: A line of best fit is not drawn here as there are clearly times when the gradient changes]

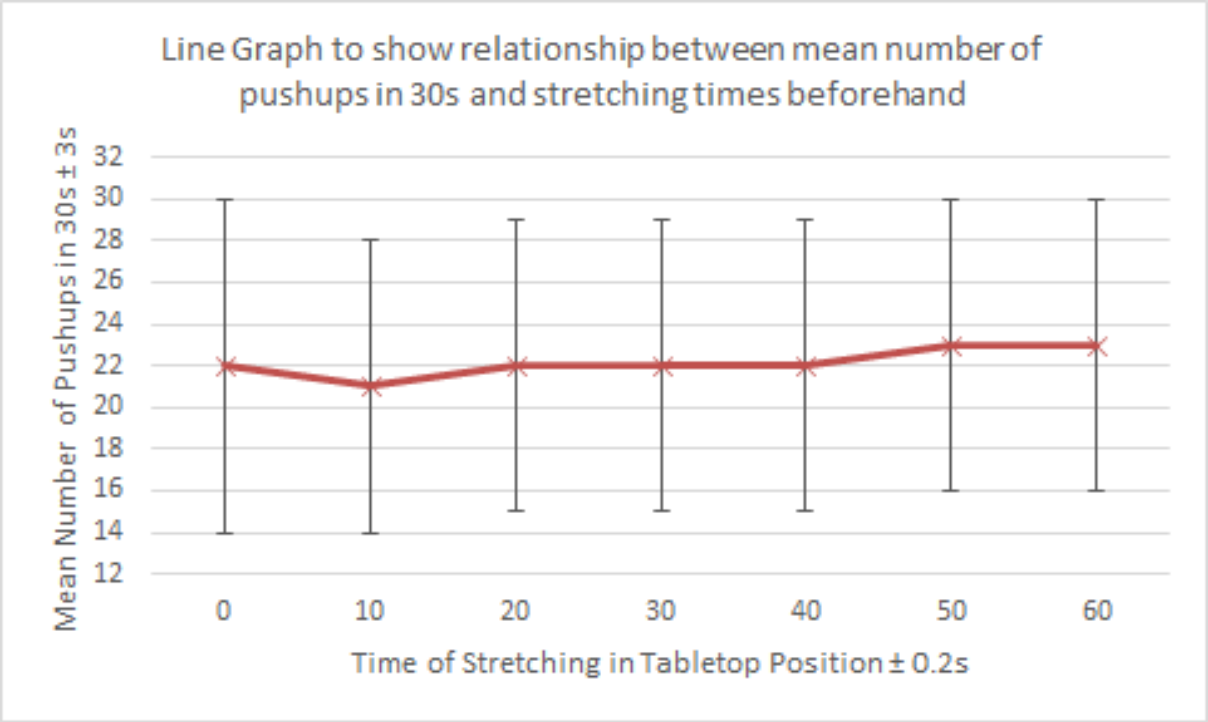


Figure 8 - Line Graph showing the Relationship between Mean Number of Pushups in 30s and Variable Stretching Times beforehand. Error Bars represent Standard Deviation.

Figure 8 shows there is a very small increase in mean pushup number as time of stretching increases (a percentage difference of 4.55% (3sf) between 0s and 60s of stretching), though the range of the error bars suggest this conclusion cannot be made to a high degree of confidence. This aligns with my prediction that the antagonist muscles became less powerful after inhibition through using up ATP, phosphocreatine and glycogen stores.

The exception to this trend is the decrease in mean pushup number between 0s and 10s and I predict this is because participants originally got tired from the stretch, regardless of any benefits, and the use of energy in order to stretch has a small, but noticeable, impact on power output/pushup number. To determine the strength of correlation between the variables I calculated Spearman's Rank Correlation Coefficient (see figure 9). It is the non-parametric alternative to Pearson's coefficient which cannot be used as my data is not normally distributed.

H_0: There is no correlation between mean pushup number & stretching time
H_1: There is a positive, non-zero correlation between pushup number & stretching time

Spearman's correlation coefficient was calculated using the following formula – equation 4:

$$Rs = 1 - \frac{6\sum D^2}{n(n^2-1)} = 1 - \frac{6\sum(Difference\ between\ rankings\ of\ two\ variables)^2}{number\ of\ participants\left((number\ of\ participants)^2-1\right)}$$

Figure 9 – Calculation of Spearman's Ranking for Mean Values

Time of Stretching (s)	Mean Number of Pushups in 30s	Stretch Rank	Pushup rank	Difference	Difference ^2
0	22	7	4.5	2.5	6.25
10	21	6	7	-1	1
20	22	5	4.5	0.5	0.25
30	22	4	4.5	-0.5	0.25
40	22	3	4.5	-1.5	2.25
50	23	2	1.5	0.5	0.25
60	23	1	1.5	-0.5	0.25

Equations 5-9:

$$\sum D^2 = 10.5$$

$$6\sum D^2 = 63$$

$$n(n^2 - 1) = 7(49 - 1) = 336$$

$$\frac{6\sum D^2}{n(n^2-1)} = \frac{63}{336} = 0.1875$$

$$Rs = 1 - \frac{6\sum D^2}{n(n^2-1)} = 1 - 0.1875 = +0.8125 = 0.813\ (3sf)$$

There is a positive correlation between the variables. At 5 degrees of freedom for a one-tailed Spearman's ranking, the critical value at 0.05 significance level is 0.714[15]. As Rs > Critical value, the null hypothesis is not accepted, and the alternative hypothesis is correct: there is a positive correlation between stretching time (in tabletop position) and number of pushups done in 30s afterwards/power output of agonist muscles.

However, figure 8 shows the standard deviation error bars overlap significantly and the mean values for each independent variable are incredibly close together, indicating the results are not "truly" significant/sufficiently different and any variations between data points *could* be attributed to chance alone.

[15] Cohen, L., & Holliday, M. (1996). *Practical statistics for students*. London, SAGE Publications Ltd doi: 10.4135/9781849209571

Conclusion

Despite a percentage difference of 4.55% between 0 and 60s of stretching and Rs exceeding the critical value, the high standard deviations for each data point decrease the validity of the conclusion that increasing stretching time increases agonist power output. Furthermore, the uncertainty in how long pushups were performed for (due to switching times between exercises) decreases the validity of my results. In an extra 3 seconds, it is entirely possible one could do one more pushup, even without changes in stretching time. Comparatively, uncertainty in stretching time is very small (±0.2) and has negligible effects on validity.

If the results were significant, the positive correlation between the two variables can be explained: with greater stretching times the muscles antagonistic to the agonist muscles working in the pushup deplete their phosphocreatine and glycogen reserves. By using up these reserves, ATP is not as readily available for myosin heads to detach from actin myofilaments and the entire process of antagonist muscle contraction is slowed down (decreasing rate/power of contraction) meaning the agonist muscles are able to fire with less competition in the opposite direction, yielding an increase in the net power able to be exerted by the agonist muscles.

Evaluation and Suggestions for Future Improvements: *Figure 10*

Limitations	*Suggestions*
Sample Size - only 10 participants were included in the investigation meaning conclusions from this experiment cannot be considered applicable to larger populations.	Using a larger sample size would make any results more reliable. Perhaps a more diverse selection of participants would yield more applicable results.
Uncertainties and Systematic Errors - As mentioned before the biggest uncertainty is the duration of time for which participants did pushups - they had to not only respond to the stopwatch, but also switch from the tabletop to pushup position potentially accounting for 3s. This is a systematic error as it skews the number of pushups recorded downward of the true value (participants may have done more pushups in the extra 3s) making measurements less *accurate*.	Use exercises that are easier to switch between so that time spent transferring between them are minimised and an accurate reflection of instantaneous effects of antagonist inhibition are still captured. For example, do bicep curls and then immediately overhead tricep extensions with the same load/dumbbell on the same arm - this involves much less energy and time to transfer between positions, but more resources and knowledge required for safe technique.
Managing the Control Variables - This is undoubtedly the factor that probably had the greatest effect on any conclusions drawn. Although participants performed pushups at similar times each day, the control variables of CNS fatigue and muscular tiredness truly vary day-by-day and can have very significant impacts on the pushup numbers.	There is no real way to avoid this when using data from the same participants over the course of multiple days. However, an alternative experiment could be done if a large enough sample size is provided and participants are similar (e.g. twins or siblings) such that one group does no stretching and the other groups stretch for variable times within the same time frame.
Despite preliminary trials pushup numbers for many participants did not change even if stretching time increased by 30s. This may indicate the increments were too small to elicit effects.	A different method can be used to inhibit antagonist muscles - instead of stretching, contract the antagonist muscles to tire them out by doing repetitions of barbell rows before pushups. These are easier to change in terms of increments via adding weights/plates.

In the future it would be worth exploring whether this effect is more pronounced in different antagonist-agonist muscle pairings – for example the lower body pairings of the hamstrings and quadriceps. Despite the limitations of the experiment, I believe the investigation had numerous strengths. Firstly, for some individual participants, increasing stretching time clearly did have an effect so for some this method of antagonist inhibition may at least be worth trying (some bodies may be more receptive of this effect). Secondly, the experimental technique ensured any potential effects of antagonist inhibition were not lost because the pushups were performed straight after the stretching was done and no other variables would have affected the number of pushups *between* these two events. The precision provided by the stopwatch, even accounting for human reaction time, was unlikely to have significant effects on result, too. Procedural errors (and random errors) were rare/non-existent with this method, too.

A note on current literature: There are not many studies to do with this topic directly. Baker and Newton (2005) explored the acute effects on power output of alternating agonist and antagonist muscles during complex strength training with 24 rugby players[16]. They demonstrated there was a statistically significant increase (about 4%) in bench press power output post-antagonist inhibition compared to the non-antagonist-inhibition group. Again, the sample size was small here too, though, so this limits the applicability of any conclusions made to the general population. I think my investigation has explored and contributed to a relatively poorly researched and little understood topic even within strength training professionals.

[16] Baker, D., & Newton, R. (2005). Acute Effect on Power Output of Alternating an Agonist and Antagonist Muscle Exercise During Complex Training. *The Journal of Strength and Conditioning Research*, *19*(1), 202. doi: 10.1519/1533-4287(2005)19<202: aeopoo>2.0.co;2

Appendix (Questionnaire, Consent Form)

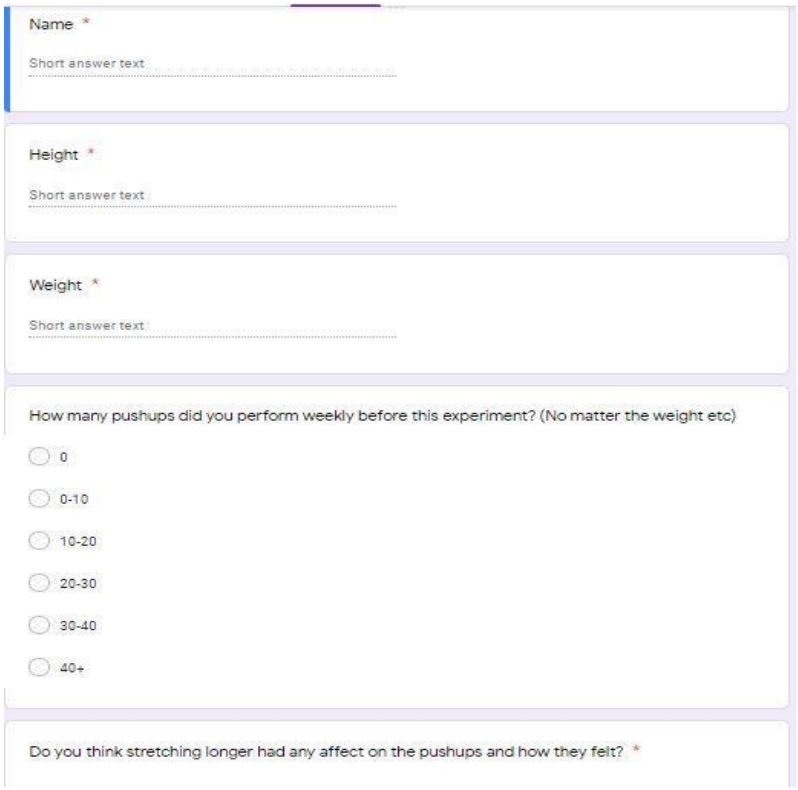
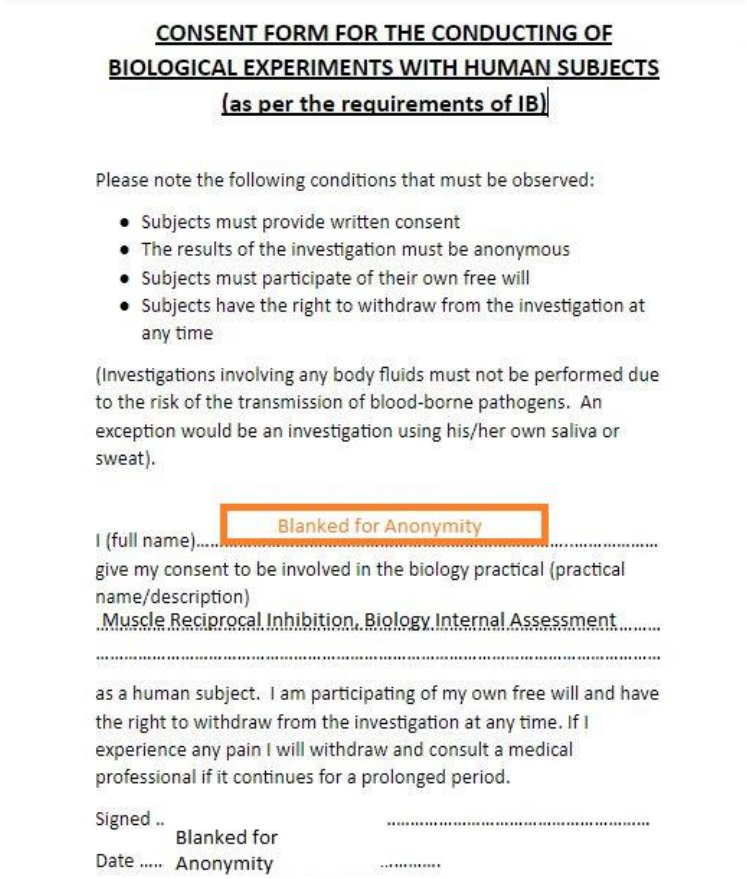


Figure 11 - Sample Questionnaire using Google Forms (2020)



CONSENT FORM FOR THE CONDUCTING OF BIOLOGICAL EXPERIMENTS WITH HUMAN SUBJECTS (as per the requirements of IB)

Please note the following conditions that must be observed:

- Subjects must provide written consent
- The results of the investigation must be anonymous
- Subjects must participate of their own free will
- Subjects have the right to withdraw from the investigation at any time

(Investigations involving any body fluids must not be performed due to the risk of the transmission of blood-borne pathogens. An exception would be an investigation using his/her own saliva or sweat).

I (full name)..... Blanked for Anonymity .....
give my consent to be involved in the biology practical (practical name/description)
Muscle Reciprocal Inhibition, Biology Internal Assessment
.....
as a human subject. I am participating of my own free will and have the right to withdraw from the investigation at any time. If I experience any pain I will withdraw and consult a medical professional if it continues for a prolonged period.

Signed .. ..
Date ..... Blanked for Anonymity .....

Figure 12 - Blank Consent Form