Measuring The Effects of Pre-Exhaust Training Using Electromyography

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This review is an examination of pre-exhaust electromyography studies, their cumulative results, and a discussion of specific shortcomings they exhibit. It concludes with a discussion on improvements future studies in the field can incorporate. Specifically, this review addresses the lack of understanding in regards to the current primary uses of PE (pre-exhaust), and EMG's (electromyography) drawbacks when used to measure PE effectiveness. Current practices of PE focus on advanced weight training athletes attempting to improve the stimulus to fatigue ratio of their lifting sessions, and reduce their risk of injury. Research thus far has mainly focused on cross sectional studies measuring acute electrical muscular activity.

The majority of these scholars found PE to not affect EMG amplitude, with the exception of two studies who did find statistically significant changes in their target muscles. The methodology of these studies is contradicted by practitioners in the field using PE, because the use of EMG is effective for acute studies, but not for longitudinal examinations. This review suggests future studies take a longitudinal approach, monitoring PE for improvements in fatigue accumulation, muscle mass and strength markers compared to control groups. By examining previous research and implementing these method changes in future work, the exercise science community can yield applicable, long term research that accurately assesses the effectiveness of PE.

Background

Pre-exhaust (PE) is a weight training strategy in which the conventional exercise order, which puts compound exercises first in a session and isolation exercises after, is reversed in order to specifically target a single muscle or muscle group. It has been utilized over the past fifty years, dating back to 1970 when it was first implemented by Arthur Jones and Vince Gironda (Romness, 2019). Jones was a strength athlete, and the founder of Nautilus, a still revered weight training equipment manufacturer. Gironda was a gym owner, author, and trainer for several notable actors at the time (Romness, 2019). Together they were the first documented trainers to implement PE in its original form. Since then, it has been used primarily in the context of sport training and muscular hypertrophy. Bodybuilders frequently use PE, which was popularized in the 1980s for quadricep hypertrophy. Athletes such as American football players often implement PE to target the chest, using the bench press as their compound movement. The general prescription is that an isolation movement is performed on the specific muscle group to, or within, two reps of failure. This is followed by a compound movement in which the targeted muscle is a limiting factor in the completion of that compound lift.

An example of this would be cable tricep pushdowns directly into overhead presses. The tricep pushdowns pre-exhaust the triceps, and they then become the limiting factor in the overhead press. In order to complete the overhead press' range of motion to full lockout, the triceps must be used. This results in exhaustion of the triceps at the end of the set, as long as near maximal to maximal effort is applied.

PE as it is currently used in hypertrophy training is directly applicable to two specific scenarios. The first and most reliable is to increase the stimulus to fatigue ratio of a training session for advanced lifters. Heavy compound lifts performed to maximal effort provide a great deal of stimulus, but also an immense amount of fatigue. For a strong individual with a large amount of muscle mass, regularly performing multiple compounds close to failure generates so much fatigue that the nervous system, joints, and connective tissues have a difficult time recovering. Accumulated fatigue may result in having to cut training blocks short in order to heal, and potential chronic injury if they do not take needed rest and recovery. Collectively, this can lead to suboptimal muscle gain and performance. Using PE is one tool for these lifters to still push chosen muscle groups with a high degree of stimulus, while decreasing the need for heavy loads. Following the previous example, an individual could perform a set of cable tricep pushdowns to failure, and then a set at 115 lbs on the overhead press, instead of starting with the overhead press at 160 lbs. Over time the conventional strategy would be placing more fatigue on the nervous system, and connective tissues of the elbow and shoulder. PE in this context is a calculated tradeoff for a small decrease in stimulus, in return for a decrease in fatigue and injury risk.

A second common implementation of PE is when one is struggling to target a specific muscle group. This often occurs in untrained individuals with their pectorals, latissimus dorsi, and gluteus maximus. For example, the glutes could be targeted via barbell hip thrusts followed by a Romanian deadlift, thus causing the glutes to become the limiting factor in said deadlift. This in theory may increase the mind muscle connection with the target muscle, and improve usage of said muscle in the deadlift, where it otherwise may not have been significantly contributing. This strategy of PE for acute increased stimulus is one of the older approaches to PE, and also the prime subject of most PE research. There is an important distinction between muscle targeting enhancement and the prior mentioned implementation of PE. The first example depicts utilizing it to decrease overall fatigue and injury risk long term. The second example demonstrates the use of PE with the goal of acutely increasing the raw stimulus to a muscle group.

Electromyography (EMG) is a tool to measure the electrical activity of a muscle. Edgar Adrian was the first to record a muscle's electrical activity, connecting electrodes from a single motor unit to a loudspeaker in 1929 (Kazamel, M., Warren P.P., 2017). In current applications of EMG, an electrode sticker is placed on the skin over the muscle, and as it is stimulated by its motor neurons, those signals result in peaks and valleys on a graphical readout. These fluctuations create a graphical amplitude, where the magnitude and frequency of the waves correspond to the intensity of exercise. When measuring an athlete's muscular activity via EMG during a typical weight training set, the EMG graph will display higher motor unit recruitment, increased firing rate, and a decreased action potential threshold. This increased intensity is expressed visually through the frequency and amplitude of the graph, as mentioned above.

In the context of EMG used to measure PE, studies have focused on either the amplitude or RMS (root mean square) values in order to determine muscle stimulus. Critically, they all focus on the acute stimulus to the muscle, and base PE efficacy on the size and firing rate of electrical signals at that moment. It must be considered that EMG cannot fully summarize the effectiveness of a training modality on its own. Factors like metabolite accumulation, blood flow, total volume, and long term programming are not measured by a single set read by EMG. In addition, a surface EMG does not measure electrical activity of muscle fibers deep below the skin's surface; those can only be measured by inserted EMG, which has not been used in any PE EMG assessments thus far (Israetel, 2021). This objective picture of EMG's strengths and weaknesses is essential to understanding the full implications of research utilizing it.

Review of Pre-Exhaust Studies

The studies completed thus far on the effectiveness of pre-exhaust (PE) using EMG as a quantitative measure are categorized here chronologically. This is due primarily to the way research methods in this field have evolved and built on each other over time. In order to understand this evolution, and where PE research methods stand today, one must understand where they began, and how they have changed up to the present day.

One of the first studies researching the efficacy of PE via EMG was conducted by Augustsson et al. in 2003. They measured EMG on the rectus femoris, vastus lateralis, and gluteus maximus with and without pre-exhaust. They concluded pre-exhaust was ineffective due to a drop in EMG amplitude in comparison to the control group for two of the measured muscles, and a statistically non-significant change in the third. Notably, only EMG amplitude compared to MVIC was used for numerical analysis. Two studies on PE followed in 2007 and 2009, both of which did not find a statistically significant increase in EMG amplitude or RMS in their target muscle, the pec major. Notably, both did see an increase in triceps brachii activity, suggesting a compensation due to the weakened pec major (Gentil et al., 2007, Brennecke et al., 2009).

The methods of these studies are crucial to understanding the larger picture of PE research, and how it has been studied moving forward. In all three studies, there is compensation by other muscle groups to “take up the slack” of the fatigued muscle. The glute activity does not reduce although the anterior leg muscle amplitudes do for Augustsson et al., and the triceps brachii, unfatigued by the prior pec fly and pec deck isolation movements, shows the only measured increase so far during the bench press for two others (Gentil et al., 2007, Brennecke et al., 2009). All three studies performed only a single isolation and single compound movement, thus not fully evaluating PE on each muscle they had measured with EMG.

In 2016, two studies had contradictory results. Soares et al. (2016) sought to rectify certain drawbacks of previous research, specifically the lack of progress markers other than EMG. They not only measured EMG but also lactate threshold, RPE, and rep counts. Similar to previous studies, they measured EMG on the pec major and triceps brachii, with the target muscle being the pec major. They concluded that PE made no statistical difference compared to traditional methods, pre-exhaust having no significant change to the target muscle in EMG, nor in RPE or blood lactate. The same year, Guarascio et al. did find a statistical increase in their target muscle, however it was the triceps brachii, not the pec major (Guarascio et al., 2016). In 2017 two more studies concluded with contradictory results. Golas et al. came to similar conclusions to Soares et al., seeing no significant increase in pec major activity despite using a different exercise selection (Golas et al., 2017). The same year, Barros et al. did find a statistically significant increase in pec major activity, following a distinct procedure. They used 30% one repetition max at a set pace for the isolation movement, and then 60% 1 RM (one repetition max) for the compound movement (Barros et al., 2017). This was closer in intensity to a warmup set than a working set, which potentially discounts the approach as traditional PE methodology. In a later study, Harlan et al.(2018) reinforced the majority of PE findings thus far, they too had no significant difference between PE and traditional methods in terms of EMG amplitude. Interestingly, there was a slight increase in slope of EMG amplitude during the PE protocol. This implies a faster rate of motor unit recruitment and firing rate increase (Harlan et al., 2018).

The studies of this decade had mixed results. One thing consistent throughout was the use of a pec fly or machine press followed by the bench press as the compound movement. This is likely due to the influence of bench press popularity in professional athlete training, particularly in sports such as American football. These studies fail to diversify the measured muscle groups or their selected movements, with the exception of the aforementioned Augustsson et al. They also continue to only measure EMG as either an average or a single point during the trials, not with multiple data points throughout the set. Like the rigid exercise selection, using a single value of EMG restricts the available data, as opposed to comparing EMG amplitude throughout the given set at multiple stages of fatigue.

One of the most recent studies to date addressed the issues of confined exercise and muscle group selection; In 2020 Fujita et al. measured the latissimus dorsi, teres major, biceps brachii, and posterior deltoid. EMG was recorded for the initial, intermediate, and final reps for the compound movement, thus providing the most complete EMG RMS measurement set yet seen. They concluded that there was no significant change between PE and traditional methods in terms of %MVIC (maximal voluntary isometric contraction), supporting the majority of previous data. This study is further distinguished by not using the pec major as its primary focus, which reinforces its conclusions.

Study	Target Muscle(s)	EMG Measured Muscles	EMG Analysis	Results (RMS/Amplitude)
Augustsson et al.	Rectus Femoris, Vastus Lateralis	Rectus Femoris, Vastus Lateralis, Gluteus Maximus	Amplitude	No Statistical Increase
Gentil et al.	Pec Major	Triceps Brachii, Anterior Deltoid, Pec Major	Amplitude	33.67% increase in Triceps Brachii activity
Brennecke et al.	Pec Major	Pec Major, Anterior Deltoid, Triceps Brachii	RMS	17.87% increase in Triceps Brachii activity
Soares et al.	Pec Major	Triceps Brachii, Pec Major	Amplitude	No Statistical Increase
Guarascio et al.	Triceps Brachii	Pec Major, Triceps Brachii	RMS	12% increase in Triceps Brachii activity
Golas et al.	Pec Major	Pec Major, Anterior Deltoid, Triceps Brachii	RMS	No Statistical Increase
Barros et al.	Pec Major	Pec Major	RMS	21% increase in Pec Major activity
Harlan et al.	Rectus Femoris	Rectus Femoris	Amplitude	No Statistical Increase
Fujita et al.	Latissimus Dorsi	Latissimus Dorsi, Teres Major, Biceps Brachii, Posterior Deltoid	Amplitude	No Statistical Increase

Figure 1: Summary of each study's target muscle, EMG measured muscles, form of EMG analysis, and study results.

Results

The majority consensus of these studies starting in 2003 and concluding in 2020 is that PE does not increase EMG amplitude, nor its RMS (RMS/amplitude depending on study) in the target muscle group. The only recorded EMG increases, save for one study, were in the tricep brachii. This occurred in three separate studies, all of which used the same machine pec fly as their isolation movement, and the bench press as their compound movement (Gentil et al., 2007, Brennecke et al., 2009, Guarascio et al., 2016). Five studies used the pec major as their target muscle, and performed the bench press as their compound movement focus. Four other studies used the vastus lateralis, rectus Femoris, latissimus dorsi, and triceps brachii as their target muscles. Whether they used the pec major or not, eight out of the nine studies measured the electrical activity of three or less muscle groups, and used only one exercise pair for all of their data. This provides a narrow band of data to pull from, and there is not a suitable sample size to determine PE's EMG response on muscle groups other than the triceps brachii, anterior deltoid, and pec major. All nine studies were acute measurements of muscular activity within a single exercise set, once again providing a sliver of the information possible throughout an entire workout, or full program mesocycle. There were no longitudinal studies performed using EMG, and only one study that had multiple target muscle groups (Augustsson et al., 2003). Within its scope, this data is valuable, however the methods prevalent here limit its practical application, and the validity of each study to claim efficacy of PE one way or another.

Discussion

Critique of Current Studies and Their Methods

Though the conclusion on EMG amplitude is well researched, the efficacy of pre-exhaust as a whole is not. Each of these studies is cross sectional, and focuses exclusively on the muscle's intensity of electrical activity in a single set. This testing methodology suggests researchers believe that acute muscular activation is indicative of the universal efficacy of PE as a training strategy. Israetel et al., Pollack et al., and NSCA's Essentials of Personal Training state that the primary implementation of PE is to reduce systemic fatigue. PE is meant to elicit a decrease in raw stimulus magnitude in return for a decrease in overall fatigue. The goal is not to increase muscle stimulation on a set to set basis. This indicates a potential disconnect between the exercise research community and the practicing exercise community. It appears that those designing these studies did not model them around PE's primary usage, and thus the answer of its efficacy remains largely absent. Although their methods are not optimal, the information gathered from these studies is still useful, it allows for the reasonable conclusion that using PE strictly to increase muscle stimulation is likely not effective. This is valuable data for trainers and athletes who may have been implementing PE with that intention. For those utilizing PE for its widely accepted purpose however, a consensus remains absent.

In addition to not focusing on the intended purpose, PE was not executed optimally in many of these studies. In "The Scientific Principles of Hypertrophy Training", it states that the compound movement following the single joint movement should be limited by the target muscle. This means one should not be able to complete the full range of motion on the compound lift without the assistance of the target muscle, thus reaching failure means you have likely exhausted said muscle. Brennecke et al., Soares et al., Golas et al., and Barros et al. all used the bench press as their compound movement. The pec major, their target muscle, is not a limiting factor in the bench press. Its activation is not necessary to perform the full range of motion. Therefore, other muscle groups such as the deltoid or triceps may fatigue before the peck, reducing efficacy of PE. This is another example of a lack of complete understanding of PE in those designing PE studies.

Another issue that plagues both current studies and future improved versions concerning PE is the placebo effect. There is no way to create a double blind or single blind scenario, because the subject must actively participate in either PE or traditional methodologies. This opens the door for bias. The placebo effect's strength scales with the degree of choice a subject has according to Tang et al. (2022), who performed a meta analysis which scrutinized the placebo effect. This means that the success lifters have gained using PE in their own training could be due to their belief in its efficacy. It also means during PE studies, the participants' own opinions either for or against pre-exhaust also have the potential to influence results. The placebo effect's strength cannot be underestimated, a meta analysis performed by Hafliðadóttir et al. in 2021 concluded that over half of over the counter and prescription drugs in circulation can have their effects attributed to placebo (Hafliðadóttir et al., 2021). Training methodologies may not play out the exact same way, but the likelihood of placebo's influence on them is high.

Recommendations

To the credit of current research, longitudinal studies to measure systemic fatigue across a full mesocycle or more of training are difficult to perform and evaluate. They have to incorporate measures of systemic fatigue, potentially involving blood work, DOMS severity, injury rates, and daily energy level perception. In addition to fatigue markers, measures of progress in both muscular hypertrophy and strength need to be taken. This is not impossible, however it requires time, financial investment, and subject participation to a much higher degree than what has been seen in the studies examined in this review. Longitudinal studies on PE have been done, and though they did not include all the factors listed above, their results suggest a more positive outlook for the effectiveness of PE in terms of muscular hypertrophy. One study which put volunteers through an 8 week strength cycle saw statistically significant increases in both 1 RM strength and cross sectional area of their target muscle (the quadriceps) in comparison to a control group not utilizing PE (Aguiar et al., 2015). Another study in 2019 used a nine week cycle, and saw a statistical increase in quadricep size in the PE group when compared to the control group (Trindade et al., 2019).

Future studies could be improved with the adoption of the following recommendations. If possible, select participants from already trained individuals. Beginners accumulate strength at unpredictable rates depending on their genetic makeup and trainability, making results inconsistent. More advanced lifters (training age greater than two to three years) are also more likely to benefit from PE implementation, and would serve as more optimal subjects.

Longitudinal studies lasting equal to or greater than eight weeks will allow enough time to potentially see changes in muscular strength, size, and fatigue accumulation (Aguiar et al., 2015). During this time rep max testing and muscle circumference measures would be useful quantitative markers. Subject feedback on session to session fatigue levels and consistent tracking of their percent improvement in each exercise would give valuable information on fatigue accumulation and progress.

Exercise selection should ensure that the target muscle is properly fatigued in the initial isolation movement, and that it is the limiting factor in the subsequent compound movement (Israetel et al. 2021). For example, if the quadriceps were the target muscle, the subject could perform leg extensions at eight to ten RPE (rate of perceived exertion) first, isolating the quadriceps and providing adequate stimulus to fatigue them. They could then perform a back squat, where the target muscles are a limiting factor, because the subject will not be able to complete a full squat without the quadriceps' activation.

A final recommendation based on the given PE EMG research is the need for communication among exercise communities. PE's primary implementation, systemic fatigue reduction, remains untested. EMG is not a sufficient marker to determine efficacy for this modality. Despite that, PE is being dismissed based on research strictly focusing on its acute effects on muscle activation. If, when designing these studies, researchers spoke with the professionals and athletes who utilize PE, their study design would likely have better reflected this training modality's efficacy.

This disconnect between the research community and the fitness/athletics community goes both ways, there are many well researched training topics which are not widely utilized in the gym. Examples of this include the role of eccentric emphasis for hypertrophy, complete daily caloric expenditure principles for weight loss, and the importance of program periodization and deloads in injury reduction and performance improvement over time. Personal trainers and gym goers alike could benefit from listening to the research community on these topics. Further collaboration between those researching and those practicing is essential to optimizing human knowledge and achievement in the realm of exercise science. Examples of this collaboration resulting in productive information come from podcast hosts including Jeff Nippard, Omar Isuf and Steve Hall, who host fitness discussions regularly with professional researchers. These individuals collaborate to cover current research and its implications on advanced training practices, providing a valuable bridge between those practicing fitness and those researching it. In a recent interview, Jeff Nippard and Dr. Bret Contreras lament the disconnect often seen between these two groups, and its impacts on topics such as training volume, set proximity to failure, and EMG research (Nippard, Contreras, 2018). The podcast platform is one medium which could be expanded to improve interdisciplinary communication in the future.

Conclusion

PE training has not been shown to result in increased EMG amplitude or RMS when compared to control groups. In the future, a longitudinal study design measuring fatigue markers and injury risk would more accurately reflect PE's effectiveness as it is currently being implemented. Using EMG to measure PE is indicative of a larger challenge in the industry, a disconnect between the practicing exercise community and the community researching exercise science. In the future, further communication and collaboration between these groups will yield more optimal training, and improved study design.

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