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JOILSON ALVES DE SOUZA LEITE JÚNIOR

RESPOSTAS NEUROMUSCULARES, TERMORREGULATÓRIAS E OXIDATIVASO TREINAMENTO DE FORÇA TRADICIONAL E EXCÊNTRICO EM ATLETAS DEPOWERLIFTING PARALÍMPICO

SÃO CRISTOVÃO
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Tese apresentada ao Programa de Pós-Graduação em Ciências Fisiológicas da Universidade Federal de Sergipe como requisito à obtenção do grau de Doutor em Ciências Fisiológicas.

Orientador: Prof. Dr. Felipe José Aidar Martins
Co-orientador: Prof. Dr. Daniel Almeida Marinho

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RESUMO

Respostas neuromusculares, termorregulatórias e oxidativas ao treinamento de força tradicional e excêntrico em atletas de powerlifting paralímpico, Joilson Alves de Souza Leite Júnior, São Cristóvão, 2026.

Introdução: O Powerlifting é uma modalidade de força máxima caracterizado pela execução de três movimentos multiarticulares: agachamento, supino reto e levantamento terra, exigindo elevado controle neuromuscular e eficiência mecânica. No contexto paralímpico, em função das características funcionais dos atletas elegíveis, apenas o exercício supino reto é realizado em competição, sendo adotadas adaptações específicas que garantem segurança, padronização técnica e equidade esportiva. **Objetivos:** Investigar os efeitos agudos e subagudos do treinamento de força tradicional e excêntrico sobre indicadores neuromusculares, mecânicos, termorregulatórios e oxidativos em atletas de powerlifting paralímpico, bem como comparar essas respostas com atletas convencionais. **Métodos:** A tese foi composta por três estudos experimentais envolvendo atletas masculinos treinados de powerlifting paralímpico. Foram avaliados indicadores neuromusculares, incluindo força isométrica máxima (FIM), taxa de desenvolvimento de força (TDF), tempo até a força isométrica máxima (TFIM) e ativação muscular por eletromiografia de superfície (sEMG) dos músculos peitoral maior (porção esternal), peitoral maior (porção clavicular) e deltoide (porção anterior) e tríceps braquial (cabeça longa). As variáveis mecânicas analisadas incluíram velocidade máxima (Vmáx), velocidade propulsiva média (VPM) e potência (POT), enquanto a resposta termorregulatória foi avaliada por meio da temperatura da pele (Tsk). O estresse oxidativo foi analisado por biomarcadores como substâncias reativas ao ácido tiobarbitúrico (TBARS) e grupos sulfidrílicos (SH). As avaliações foram realizadas antes, imediatamente após, 24h e 48h após sessões de treinamento tradicional e excêntrico, com protocolos baseados em cargas relativas de 1RM. **Resultados:** Os resultados demonstraram que o treinamento excêntrico promoveu respostas fisiológicas mais intensas, caracterizadas por aumento da temperatura da pele, maior elevação de marcadores de estresse oxidativo e maiores adaptações neuromusculares em momentos específicos, embora associado a maior fadiga e recuperação mais prolongada. Por outro lado, o treinamento tradicional apresentou respostas mais estáveis, com recuperação mais rápida dos indicadores de desempenho. **Conclusão:** O treinamento excêntrico configura-se como uma estratégia eficaz para promover adaptações neuromusculares e fisiológicas relevantes em atletas de powerlifting paralímpico, embora demande maior controle da fadiga e do processo de recuperação. Já o treinamento tradicional apresenta-se como uma abordagem mais estável e adequada para períodos de manutenção e preparação competitiva. A combinação estratégica entre os métodos pode otimizar o desempenho esportivo, respeitando as especificidades fisiológicas e funcionais dos atletas paralímpicos, reforçando a necessidade de individualização da prescrição do treinamento.

Descritores: treinamento de força; treinamento excêntrico; powerlifting paralímpico; respostas neuromusculares; estresse oxidativo.

ABSTRACT

Neuromuscular, thermoregulatory, and oxidative responses to traditional and eccentric strength training in Paralympic powerlifting athletes, Joilson Alves de Souza Leite Júnior, São Cristóvão, 2026.

Introduction: Powerlifting is a maximal strength sport characterized by the execution of three multi-joint movements: the squat, bench press, and deadlift, requiring high levels of neuromuscular control and mechanical efficiency. In the Paralympic context, due to the functional characteristics of eligible athletes, only the bench press is performed in competition, with specific adaptations implemented to ensure safety, technical standardization, and competitive equity. **Objectives:** To investigate the acute and subacute effects of traditional and eccentric strength training on neuromuscular, mechanical, thermoregulatory, and oxidative indicators in Paralympic powerlifting athletes, as well as to compare these responses with those of conventional athletes. **Methods:** This thesis consisted of three experimental studies involving trained male Paralympic powerlifting athletes. Neuromuscular indicators were assessed, including maximum isometric force (MIF), rate of force development (RFD), time to maximum isometric force (TMIF), and muscle activation measured by surface electromyography (sEMG) of the pectoralis major (sternocostal and clavicular portions), anterior deltoid, and triceps brachii (long head). Mechanical variables included peak velocity (Vmax), mean propulsive velocity (MPV), and power output (POT), while thermoregulatory responses were evaluated באמצעות skin temperature (Tsk). Oxidative stress was assessed using biomarkers such as thiobarbituric acid reactive substances (TBARS) and sulfhydryl groups (SH). Measurements were performed at baseline, immediately post-exercise, and at 24 and 48 hours following traditional and eccentric training sessions, using protocols based on relative loads (%1RM). **Results:** The findings demonstrated that eccentric training elicited more pronounced physiological responses, characterized by increased skin temperature, greater elevations in oxidative stress markers, and enhanced neuromuscular adaptations at specific time points, although it was also associated with greater fatigue and prolonged recovery. In contrast, traditional training produced more stable responses, with faster recovery of performance indicators. **Conclusion:** Eccentric training appears to be an effective strategy for promoting relevant neuromuscular and physiological adaptations in Paralympic powerlifting athletes, although it requires careful management of fatigue and recovery. Conversely, traditional training represents a more stable approach, particularly suitable for maintenance phases and competitive preparation. A strategic combination of both methods may optimize athletic performance while respecting the physiological and functional specificities of Paralympic athletes, reinforcing the need for individualized training prescription.

Keywords: strength training; eccentric training; Paralympic powerlifting; neuromuscular responses; oxidative stress.

RESUMO VOLTADO PARA A SOCIEDADE

Respostas neuromusculares, termorregulatórias e oxidativas ao treinamento de força tradicional e excêntrico em atletas de powerlifting paralímpico, Joilson Alves de Souza Leite Júnior, São Cristóvão, 2026.

O que é o estudo?

O Powerlifting Paralímpico é uma modalidade de força em que atletas com deficiência nos membros inferiores realizam o exercício do supino reto adaptado. Como o esporte exige níveis altíssimos de força, controle muscular e estabilidade nos membros superiores, treinadores utilizam diferentes métodos de treinamento para potencializar os resultados. Este trabalho buscou investigar e comparar os efeitos de dois métodos de treino: o Treinamento Tradicional e o Treinamento Excêntrico (que foca na fase de descida do peso com maior carga) sobre o rendimento, a fadiga muscular, a temperatura do corpo e o estresse oxidativo dos atletas.

Como a Pesquisa Foi Realizada?

A tese foi estruturada em três estudos experimentais com atletas masculinos de alto rendimento no Powerlifting Paralímpico (competidores de nível nacional/internacional):

- Estudo 1 (12 atletas): Avaliou a força máxima estática, o tempo para atingir a força, a temperatura da pele (para medir inflamação/fadiga) e a atividade elétrica dos músculos.
- Estudo 2 (19 atletas): Analisou a força máxima, a velocidade do movimento, a potência muscular e a resposta da temperatura corporal.
- Estudo 3 (15 atletas): Investigou os marcadores de estresse oxidativo (desgaste celular) e a capacidade de gerar força rápida.

Em todos os experimentos, os atletas foram testados em quatro momentos: antes do treino, imediatamente após, 24 horas e 48 horas depois.

Principais Achados:

- Treinamento Tradicional: Apresentou respostas mais estáveis. Os atletas demonstraram uma recuperação mais rápida da força, velocidade e potência, além de menor desgaste muscular acumulado.
- Treinamento Excêntrico (Ênfase na Descida da Carga): Provocou respostas fisiológicas mais intensas. Aumentou a temperatura muscular, gerou maior estresse

oxidativo e promoveu estímulos mais profundos de força e adaptação muscular em momentos específicos. No entanto, por exigir mais do organismo, também causou maior fadiga e um processo de recuperação mais lento.

Conclusão e Aplicação Prática:

Ambos os métodos são valiosos, mas devem ser usados de forma estratégica e individualizada no planejamento dos treinos:

- Fases de Ganho de Força: O Treinamento Excêntrico é uma ferramenta potente para estimular ganhos mais profundos e adaptar a musculatura contra o estresse intenso.
- Fases de Competição: O Treinamento Tradicional é o mais indicado para momentos próximos às provas e períodos de manutenção, pois garante menor fadiga e pronta recuperação dos atletas.

A combinação planejada dessas duas metodologias otimiza a evolução do desempenho esportivo paralímpico com segurança, prevenindo lesões e respeitando os limites do corpo.

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ESTUDO 2: EFEITOS AGUDOS DO TREINO EXCÊNTRICO VERSUS TRADICIONAL SOBRE FORÇA ISOMÉTRICA, POTÊNCIA E TERMORREGULAÇÃO EM ATLETAS DE *POWERLIFTING* PARALÍMPICO.

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ESTUDO 3: EFEITO DO TREINAMENTO EXCÊNTRICO NA MODULAÇÃO DO ESTRESSE OXIDATIVO E NA MELHORIA DA PERFORMANCE EM ATLETAS DE *POWERLIFTING* PARALÍMPICO.

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1 INTRODUÇÃO GERAL

1.1 O ESTADO DA ARTE

A atividade física é compreendida como qualquer movimento corporal produzido pela musculatura esquelética que resulte em gasto energético acima dos níveis de repouso, sendo considerado um componente fundamental para a saúde e o desempenho humano (Caspersen et al., 1985).

O exercício físico constitui uma subcategoria da atividade física, caracterizando por ser planejado, estruturado, repetitivo e orientado, com objetivos específicos, sendo eles manutenção, desenvolvimento ou melhora de componentes da aptidão física, incluindo capacidades cardiorrespiratórias, neuromusculares, morfológicas, metabólicas e motoras (ACSM, 2019; Caspersen et al., 1985). No contexto esportivo, o exercício físico assume papel central na preparação sistemática do atleta, sendo organizado em programas de treinamento com base em princípios científicos e controle de carga.

O *Powerlifting* é uma modalidade de força máxima caracterizado pela execução de três movimentos multiarticulares: agachamento, supino reto e levantamento terra, exigindo elevado controle neuromuscular e eficiência mecânica. Já no *Powerlifting* Paralímpico (PP), a atletas com deficiências físicas permanentes, como amputações de membros inferiores, más-formações congênitas, lesões medulares, baixa estatura e condições neurológicas específicas. Independentemente do tipo de deficiência, o objetivo principal é levantar a maior carga possível em uma única tentativa válida de supino reto, respeitando os critérios técnicos estabelecidos pela federação internacional. Essa configuração reforça a importância de estratégias de treinamento individualizadas, que considerem as particularidades clínicas, neuromusculares e biomecânicas de cada atleta, bem como suas respostas fisiológicas ao esforço de alta intensidade.

A modalidade de PP é atualmente regulamentada em nível internacional pelo *World Para Powerlifting* (WPPO), entidade vinculada ao *International Paralympic Committee* (IPC), com sede em Bonn, Alemanha, enquanto, no Brasil, sua organização e desenvolvimento são conduzidos pelo Comitê Paralímpico Brasileiro (CPB), com sede em São Paulo, Brasil. As competições oficiais reconhecidas pelo WPPO seguem regras e regulamentos técnicos padronizados, atualizados periodicamente, que definem critérios rigorosos de execução do movimento, utilização de equipamentos, requisitos técnicos e sistemas de pontuação, aplicáveis a todas as competições sancionadas, incluindo o ciclo competitivo 2025-2028, que engloba eventos internacionais como Campeonatos Mundiais, Copas do

Mundo, etapas regionais e culmina nos Jogos Paralímpicos e demais competições multiesportivas associadas.

Nesse contexto, homens e mulheres competem em categorias de peso corporal distintas, sendo a precisão biomecânica e o controle neuromuscular determinantes para a validação de cada tentativa. Durante as competições, os atletas realizam exclusivamente o exercício supino reto em um banco especialmente projetado, obedecendo a uma sequência padronizada de comandos oficiais, que inclui a retirada da barra com os cotovelos estendidos, a descida controlada até a parada visível na região do peitoral, a manutenção estável da barra nessa posição e a subsequente extensão completa e simultânea dos cotovelos; qualquer assimetria, instabilidade ou falha técnica resulta na invalidação do levantamento.

No que se refere à elegibilidade esportiva, o WPPO reconhece diferentes tipos de deficiência física, como comprometimento da força ou potência muscular, limitações permanentes da amplitude de movimento, deficiências ou discrepâncias no comprimento dos membros inferiores, baixa estatura e condições neurológicas associadas a alterações dos tônus ou da coordenação motora (*WPPO, 2025*, s.d.).

A classificação dos atletas ocorre exclusivamente por categorias de peso corporal, sem subdivisões funcionais adicionais, o que eleva substancialmente o nível de competitividade e exige elevado desempenho neuromuscular dos participantes. Competem homens e mulheres com deficiência nos membros inferiores, baixa estatura e paralisados cerebrais. Cada competidor possui três tentativas, objetivando levantar a maior carga válida como resultado final. A participação na competição é livre para todos os indivíduos elegíveis, nas categorias: novato (15 a 17 anos), próxima geração (18 a 20 anos), elite (+15 anos) e lenda (+45 anos) (WPPO, 2025, s.d.).

Durante o movimento, os principais músculos envolvidos são: o peitoral maior (porções esternal e clavicular), o deltóide anterior e o tríceps braquial (cabeça longa). A execução do supino reto consiste na fase excêntrica e concêntrica. Na fase excêntrica, o indivíduo remove a barra do rack, posiciona os braços com os cotovelos estendidos e travados, e ao sinal do árbitro, desce a barra até tocar o peito, realizando uma parada visível. A fase concêntrica consiste no retorno a posição inicial, até que os braços estejam novamente estendidos e os cotovelos travados. O atleta deve permanecer estático nesta posição até que o árbitro sinalize o retorno da barra ao rack. As categorias presentes na modalidade estão descritas na tabela 1, juntamente com a faixa de peso corporal limítrofe:

Tabela 1: Categorias por peso corporal.

Gênero	Categoria	Peso Corporal Mímino (kg)	Peso Corporal Máximo (kg)
Feminino	**Até 41.0kg**	-	41.0
	Até 45.0kg	41.1	45.0
	Até 50.0kg	45.1	50.0
	Até 55.0kg	50.1	55.0
	Até 61.0kg	55.1	61.0
	Até 67.0kg	61.1	67.0
	Até 73.0kg	67.1	73.0
	Até 79.0kg	73.1	79.0
	Até 86.0kg	79.1	86.0
	Acima de 86.0kg	86.1	-
Masculino	**Até 49.0kg**	-	49.0
	Até 54.0kg	49.1	54.0
	Até 59.0kg	54.1	59.0
	Até 65.0kg	59.1	65.0
	Até 72.0kg	65.1	72.0
	Até 80.0kg	72.1	80.0
	Até 88.0kg	80.1	88.0
	Até 97.0kg	88.1	97.0
	Até 107.0kg	97.1	107.0
	Acima de 107.0kg	107.1	-

Fonte: Adaptado do livro de regras do *Powerlifting* Paralímpico (*WPPO, 2025*, s.d.).

A predominância do uso dos membros superiores impõe demandas neuromusculares elevadas, tornando o controle motor, a estabilidade articular e a produção de força fatores críticos para o desempenho competitivo. No estágio inicial do treinamento, evidências indicam que alterações no sistema nervoso precedem mudanças morfológicas, com aumento da excitabilidade corticospinal, do *drive* neural central e da eficiência no controle da contração muscular, contribuindo de forma determinante para os ganhos iniciais de força (Wilson et al., 2023).

No âmbito periférico, observa-se a modulação da taxa de disparo das unidades motoras, o aprimoramento da sincronização e a maior estabilidade no recrutamento neural, fatores diretamente associados à capacidade de produção e ao rápido desenvolvimento de força, mesmo em tarefas de alta exigência mecânica (Del Vecchio et al., 2019). À medida que o treinamento progride, essas adaptações neurais se integram a mudanças estruturais, como hipertrofia muscular e reorganização funcional dos músculos agonistas e sinergistas, resultando em maior eficiência mecânica e refinamento do controle motor, aspectos particularmente relevantes em atletas paralímpicos submetidos a rigorosos critérios técnicos de execução.

O treinamento de alta intensidade induz adaptações multidimensionais no sistema neuromuscular, como hipertrofia muscular, mudanças na espessura e arquitetura das fibras e reorganização funcional dos músculos agonistas e sinergistas que em conjunto com ajustamentos neurais contribuem para maior eficiência mecânica e controle do gesto esportivo (Rong et al., 2025).

O monitoramento dos atletas inclui dois propósitos importantes, mas sobrepostos: o manejo da fadiga e a eficácia do programa, envolvendo a manipulação do volume e da intensidade, portanto, é importante discutir os métodos usados para monitorar a força e os estímulos de treino a fim de beneficiar o desempenho motor geral do atleta (Suchomel et al., 2021). Diante desse cenário, observa-se um crescente interesse científico em investigar os efeitos de distintas estratégias de treinamento resistido no PP, especialmente no que se refere à comparação entre o método de Treino Tradicional (TT), composto por 5 séries de 5 repetições máximas (RM) (Austin & Mann, 2012), e o método de Treino Excêntrico (TE) composto por 5 séries de 5 repetições máximas (Taber et al., 2021a).

A compreensão integrada das respostas mecânicas, neuromusculares, térmicas e bioquímicas torna-se fundamental para o aprimoramento do desempenho esportivo e para o desenvolvimento de programas de treinamento mais seguros, eficazes e individualizados, constituindo o eixo central das investigações que fundamentam a presente tese.

Diversos métodos têm sido propostos para monitoramento da carga de treinamento, cada um com diferentes níveis de sensibilidade e aplicabilidade no contexto do desempenho esportivo. Praticantes de força e condicionamento têm acesso a uma grande variedade de métodos que podem ser usados para monitorar e ajustar a intensidade do treino. No entanto, é importante compreender as vantagens e desvantagens de cada método. Muitos dos métodos podem ser usados juntos para fornecer uma compreensão maior do estado de treinamento do atleta. Além disso, futuras estratégias de monitoramento podem contribuir para essas medidas focadas nos resultados dos atletas (Suchomel et al., 2021).

1.2 INTRODUÇÃO

A execução de movimentos, sejam simples ou complexos, constitui a principal resposta motora do sistema nervoso frente a estímulos internos ou externos, culminando na contração muscular. No sistema motor somático, essa função é organizada por estruturas com diferentes papéis: os músculos esqueléticos atuam como elementos efetuadores; os motoneurônios da medula espinal e do tronco encefálico funcionam como ordenadores; o cerebelo e os núcleos da base desempenham o controle da execução; e o córtex motor é responsável pelo planejamento das ações. O processo contrátil ocorre por meio do deslizamento de proteínas especializadas dentro das fibras musculares, desencadeado pela chegada do potencial de ação ao motoneurônio, liberação de neurotransmissores e ativação

de proteínas do citoesqueleto (Aires, 2018; Boron & Boulpaep, 2020; Ganong, 2014; SILVERTHORN, D. U., 2017).

Com base na teoria da ponte cruzada da contração muscular, a força exercida pelo músculo é gerada pela interação entre actina e miosina, o que resulta na tradução das proteínas miofibrilares umas em relação às outras. No entanto, quando as fibras musculares são alongadas em uma contração excêntrica, as ligações de actomiosina provavelmente são interrompidas mecanicamente, em vez de sofrerem um descolamento dependente de ATP (Flitney & Hirst, 1978). Esse perfil de carga impõe tensões nas estruturas envolvidas e pode contribuir para o dano tecidual que ocorre com contrações excêntricas (Enoka, R. M., 2015). Diversas anomalias estruturais são evidentes nos músculos após o exercício, especialmente em exercícios que envolvem contrações excêntricas, como perturbação sarcolemática, dilatação do sistema de túbulos transversos, distorção dos componentes miofibrilares, fragmentação do retículo sarcoplasmático, lesões da membrana plasmática, danos no citoesquelético, alterações na matriz extracelular da miofibra e mitocôndrias inchadas (Enoka, 1996; Fridén & Lieber, 1992).

As fibras musculares esqueléticas são alongadas, multinucleadas e dispostas em feixes revestidos por tecido conjuntivo, que se prolonga até formar os tendões. Em seu interior, as miofibrilas apresentam filamentos finos, compostos principalmente por actina, tropomiosina e troponina e filamentos grossos de miosina, arranjados em unidades repetitivas chamadas sarcômeros, responsáveis pela aparência estriada do músculo. Estruturas como o retículo sarcoplasmático e os túbulos T integram o acoplamento excitação-contração por meio da regulação da liberação de cálcio (Ca^{2+}). Proteínas como titina, nebulina e distrofina mantêm a integridade e a elasticidade do sarcômero, e mutações em seus genes podem resultar em doenças neuromusculares (Aires, 2018; Boron & Boulpaep, 2020; Koeppen & Stanton, 2018).

A junção neuromuscular é o ponto de comunicação entre o terminal axônico do motoneurônio e a placa motora da fibra muscular, onde ocorre a transmissão sináptica por meio da liberação do neurotransmissor acetilcolina (ACh). Essa estrutura possui botões sinápticos contendo vesículas com ACh, canais de cálcio dependentes de voltagem e mitocôndrias. Quando o potencial é deflagrado e chega à terminação nervosa, a ACh é liberada e se liga a receptores nicotínicos nas dobras da membrana pós-sináptica, permitindo o influxo de Na^+ e o efluxo de K^+, gerando o potencial da placa motora. Ao atingir o limiar de excitação, são ativados canais de Na^+ dependentes de voltagem, propagando o potencial de ação pela fibra muscular,

com velocidade dependente da bainha de mielina, desencadeando a liberação de Ca^{2+} do retículo sarcoplasmático. Esse cálcio se liga à troponina, formando o complexo Troponina C, promovendo o deslocamento da tropomiosina e permitindo a interação actina-miosina, responsável pela contração muscular. O relaxamento ocorre com o retorno do Ca^{2+} ao retículo sarcoplasmático, restabelecendo o estado de repouso (Aires, 2018; Ganong, 2014; SILVERTHORN, D. U., 2017).

A intensidade da contração muscular depende da quantidade de fibras ativadas e da frequência dos estímulos nervosos. O recrutamento progressivo de unidades motoras caracteriza a somação espacial, enquanto estímulos sucessivos em alta frequência, antes do relaxamento completo, resultam em somação temporal, podendo gerar tetania. Além disso, o comprimento inicial do músculo influencia a força produzida: há um comprimento ótimo que maximiza a sobreposição de actina e miosina, favorecendo a geração de tensão (Boron & Boulpaep, 2020; Ganong, 2014).

As fibras musculares esqueléticas se dividem, classicamente, em fibras do tipo I (oxidativas lentas) e do tipo II, sendo estas subdivididas em IIa (oxidativas-glicolíticas rápidas) e IIx (glicolíticas rápidas), com propriedades estruturais e funcionais distintas. As fibras tipo I, de metabolismo oxidativo, possuem alta densidade mitocondrial, grande quantidade de mioglobina e enzimas oxidativas, sendo resistentes à fadiga e adaptadas à atividade aeróbia.

As fibras tipo II, com metabolismo predominantemente glicolítico, são adaptadas a esforços de alta intensidade e curta duração. Dentro desse grupo, as fibras IIa possuem características intermediárias, enquanto as IIb, menos vascularizadas e com menor quantidade de mitocôndrias, são especializadas em contrações explosivas e curtas (Aires, 2018; BERNE, R. M. & et al., 2020; SILVERTHORN, D. U., 2017).

As características das fibras musculares influenciam diretamente o funcionamento das unidades motoras. Fibras tipo I necessitam de menor frequência de estimulação para fundir contrações (12-15Hz), enquanto fibras tipo II demandam frequências mais elevadas (>40Hz). Essas diferenças estão associadas à expressão de isoformas específicas de proteínas contráteis e reguladoras, moduladas pela interação trófica entre motoneurônios e fibras musculares (Aires, 2018; Ganong, 2014; SILVERTHORN, D. U., 2017).

As células musculares, em geral, convertem energia química do Trifosfato de Adenosina (ATP) em energia mecânica para gerar força e movimento, incluindo locomoção, bombeamento cardíaco e movimentação de órgãos ocos. Há três tipos

principais: o músculo esquelético, voluntário e estriado; o cardíaco, estriado e involuntário; e o liso, involuntário e não estriado. A força contrátil, em todos os casos, resulta da interação actina-miosina, regulada pela variação de cálcio intracelular. No músculo esquelético, as fibras estão organizadas em fascículos envolvidos por camadas de tecido conjuntivo (endomísio, perimísio e epimísio) que transmitem força aos tendões e auxiliam na proteção mecânica (Boron & Boulpaep, 2020; Ganong, 2014; Koeppen & Stanton, 2018).

O sarcômero, unidade funcional do músculo esquelético, é limitado pelas linhas Z e composto por filamentos finos e grossos, cuja organização gera o padrão estriado. O retículo sarcoplasmático, associado aos túbulos transversos (T), controla a disponibilidade de Ca^{2+} para a contração muscular. Proteínas estruturais como titina, nebulina, miomesina e proteína C conferem estabilidade, alinhamento e elasticidade, assegurando a eficiência contrátil (Koeppen & Stanton, 2018; SILVERTHORN, D. U., 2017).

O processo de contração muscular voluntária se inicia no sistema nervoso central (SNC), particularmente no córtex motor primário (área 4 de Brodmann), onde os comandos motores são gerados. Esses sinais descendem pela medula espinal através dos tratos corticoespinais, especialmente o trato corticoespinal lateral, que decussa nas pirâmides bulbares e sinapsa com os neurônios motores alfa (α), localizados nos cornos anteriores da medula espinal (KANDEL, E. R. & et al., 2014).

Esses motoneurônios α transmitem potenciais de ação ao longo de seus axônios até a junção neuromuscular, onde ocorre a liberação do neurotransmissor acetilcolina (ACh). A ACh se liga a receptores nicotínicos do tipo N1 na membrana da fibra muscular, promovendo a despolarização local e gerando um potencial de ação muscular, que se propaga pelo sarcolema e entra nos túbulos transversos (T) (GUYTON, A. C. & HALL, J. E., 2021).

A propagação do potencial de ação nos túbulos T ativa os canais de Ca^{2+} dependentes de voltagem, conhecidos como receptores diidropiridínicos (DHP) que estimulam a abertura dos receptores de rianodina tipo 1 (RyR1) localizados nas cisternas do retículo sarcoplasmático (RS). Essa ativação promove a liberação maciça de íons Ca^{2+} no citosol, elevando suas concentrações de cerca de 100nM para até 10µM (Boron & Boulpaep, 2020). Em teoria, essa elevação abrupta do Ca^{2+} intracelular é altamente regulada e depende da integridade dos canais DHP-RyR1 acoplados mecanicamente, bem como da atividade basal das proteínas calsequestrina, triadina e junctina que ajudam na retenção de Ca^{2+} no RS.

O aumento do Ca^{2+} citosólico permite sua ligação à troponina C,

desencadeando uma mudança conformacional no complexo troponina-tropomiosina. Esse processo libera os sítios de ligação da actina, permitindo que as cabeças de miosina, previamente ativadas pela hidrólise de ATP, se liguem aos filamentos finos de actina (ALBERTS, B. & et al., s.d.). A força contrátil depende diretamente da concentração de Ca^{2+} livre e sua remoção eficiente após a contração é garantida principalmente pelas bombas SERCA (Ca^{2+}-ATPases), localizadas na membrana do retículo sarcoplasmático, com auxílio de proteínas como a fosfolamban que modulam sua atividade (Boron & Boulpaep, 2020).

O processo contrátil segue o chamado ciclo das pontes cruzadas. A cabeça de miosina, ligada ao difosfato de adenosina (ADP) e fosfato inorgânico (Pi), interage com a actina, promovendo o "golpe de força" (*power stroke*) após a liberação do Pi. Em seguida, o ADP é liberado, e a miosina permanece fortemente ligada à actina até que uma nova molécula de ATP se ligue, promovendo o desligamento e reinício do ciclo (BERNE, R. M. & et al., 2020; Nelson & Cox, 2021).

Esse ciclo se repete milhares de vezes por segundo durante a contração muscular, sem alteração no comprimento dos filamentos, mas com encurtamento do sarcômero, fenômeno descrito pela teoria dos filamentos deslizantes (GUYTON, A. C. & HALL, J. E., 2021).

Quando o estímulo neural cessa, a acetilcolina é degradada por ação da enzima acetilcolinesterase, encerrando a transmissão sináptica. O Ca^{2+} é recaptado ativamente pelo retículo sarcoplasmático por meio das bombas SERCA (Ca^{2+}-ATPases), permitindo o retorno do complexo troponina-tropomiosina à posição de repouso e cessando a contração (ALBERTS, B. & et al., s.d.; Boron & Boulpaep, 2020). O sequestro eficiente do Ca^{2+} intracelular é fundamental não só para o relaxamento muscular, mas também para prevenir sobrecarga de cálcio, que pode levar a dano celular e disfunção mitocondrial.

A contração muscular depende de ATP para dissociação actina-miosina, recarga da cabeça de miosina, recaptura de Ca^{2+} e manutenção do potencial de membrana. A falência na ressíntese de ATP, como na isquemia ou na morte, leva à rigidez cadavérica (*rigor mortis*), devido à permanência das pontes cruzadas (GUYTON, A. C. & HALL, J. E., 2021).

O recrutamento das unidades motoras obedece ao princípio do tamanho, descrito por Henneman (Somjen et al., 1965). As unidades motoras menores que inervam fibras tipo I são ativadas primeiro. À medida que aumenta a demanda de força, unidades maiores com fibras tipo II são recrutadas sequencialmente (KANDEL, E. R. & et al., 2014). Além disso, a frequência dos potenciais de ação

influencia a força gerada, podendo atingir tetania em altas frequências (GUYTON, A. C. & HALL, J. E., 2021)As adaptações neuromusculares ao treinamento resistido seguem uma cronologia definida. Nas fases iniciais (4 a 6 semanas), predominam adaptações neurais: maior recrutamento motor, aumento da excitabilidade central, sincronização entre unidades motoras e inibição recíproca reduzida (Kraemer & Ratamess, 2004). Com o tempo, surgem as adaptações estruturais: aumento da área de secção transversa, densidade de miofibrilas e síntese proteica, especialmente em fibras do tipo II (BERNE, R. M. & et al., 2020).

O lactato, subproduto da glicólise anaeróbia, atua como regulador do potencial de hidrogênio (pH) e como substrato energético. Sua produção e remoção envolvem as isoformas dos transportadores de monocarboxilato (MCT-1 e MCT-4). As fibras tipo II produzem mais lactato, enquanto as fibras tipo I são mais eficientes em consumi-lo, sendo esse equilíbrio crucial para o desempenho físico e recuperação (Brooks, 2000). Acompanhando essas mudanças, pode haver um aumento gradual da dor muscular, atingindo o pico 24 a 48 horas após o exercício. Esse efeito é conhecido como dor muscular de início retardado (DMIT) (Enoka, 1996). Primeiro, a DMIT parece estar relacionada mais a uma resposta inflamatória do que à aparência de dano estrutural (L L Smith, 1991). Segundo, ganhos de força muscular resultantes de contrações excêntricas parecem estar relacionados às mudanças na ativação neural e não pelo aumento da resposta hipertrófica (Dudley et al., 1991). Embora o papel dos mecanismos neurais no ganho de força não seja exclusivo das contrações excêntricas, essa ação muscular parece ser maior para esse tipo de atividade.

1.3 TREINAMENTO RESISTIDO

O treinamento resistido (TR) é uma das formas mais antigas e eficazes de desenvolvimento das capacidades físicas do ser humano, tendo evoluído de práticas empíricas para uma abordagem científica sistematizada. Inicialmente associado ao levantamento de pesos em contextos militares, atléticos e culturais, o treinamento com sobrecarga passou a ser amplamente estudado e aplicado com objetivos diversos, que vão desde a promoção da saúde até o alto rendimento esportivo (Fleck, 2014). Nas últimas décadas, a consolidação de sua base fisiológica permitiu o refinamento das metodologias e estratégias, tornando-se um componente essencial nos programas de treinamento.

O TR é uma ferramenta potente para indução de adaptações morfofuncionais no organismo humano. Diversos estudos evidenciam seu impacto positivo na força

muscular, no controle motor, na densidade óssea, na composição corporal e até em parâmetros metabólicos e cardiovasculares (DANTAS, E. H. M., 2013; Kraemer & Ratamess, 2004). Além disso, a sua aplicação adequada respeita princípios como a individualidade biológica, a especificidade, a sobrecarga progressiva, a interdependência volume-intensidade, a adaptação anatômica, a variabilidade e a reversibilidade (BOMPA, T. O. & BUZZICHELLI, C. A., 2020; PLATONOV, V. N., 2008).

Na periodização do treinamento, (MATVEEV, L. P., 1981; VERKHOSHANSKY, Y. V., 2000) propuseram modelos que visam otimizar o desempenho físico a partir de ciclos de carga e recuperação cuidadosamente planejados. Essa organização busca evitar o esgotamento neuromuscular, o *overtraining* e promover a supercompensação, sendo fundamental para atletas. O entendimento dessas estruturas é imprescindível para o desenho de intervenções que promovam não apenas ganhos de força e potência, mas também adaptação neural, metabólica e estrutural dos sistemas envolvidos.

A complexidade do TR exige uma compreensão aprofundada das variáveis como intensidade, volume, densidade, intervalo entre séries, velocidade de execução e seleção dos exercícios (Fleck, 2014). Cada uma dessas variáveis interage de maneira sinérgica para produzir estímulos fisiológicos específicos, com impacto direto nos mecanismos de recrutamento e fadiga muscular, ativação das vias de sinalização celular e expressão gênica relacionada à hipertrofia e à adaptação funcional.

Para compreender plenamente os efeitos do TR, torna-se essencial analisar a natureza das ações musculares envolvidas na execução dos movimentos. As contrações concêntricas, excêntricas e isométricas apresentam características biomecânicas e fisiológicas distintas, influenciando diretamente o tipo de adaptação esperada. Cada uma dessas formas de contração impõe demandas específicas ao sistema neuromuscular, impactando tanto as respostas agudas quanto as adaptações crônicas ao treinamento.

Nesse contexto, é imprescindível aprofundar o entendimento sobre a musculatura esquelética estriada, estrutura responsável pelas ações motoras voluntárias e pela produção de força. Essa musculatura é regulada por um sistema altamente integrado que envolve mecanismos neurológicos, bioquímicos e moleculares. A compreensão dos fundamentos fisiológicos da contração muscular e suas adaptações ao treinamento de força é essencial para a aplicação prática em

contextos como o desempenho atlético e a reabilitação de indivíduos com deficiência física (Boron & Boulpaep, 2020; GUYTON, A. C. & HALL, J. E., 2021).

Durante as contrações excêntricas, a carga no músculo é maior do que a força desenvolvida por ele, e o músculo é alongado, produzindo uma contração de alongamento. O exercício excêntrico é caracterizado por microlesões musculares e maior tensão mecânica em comparação com contrações concêntricas ou isométricas e, portanto, pode resultar em maiores adaptações musculares. Embora todas as formas de exercício possam induzir adaptações estruturais e funcionais relevantes, o exercício excêntrico tem se destacado por promover respostas mais expressivas sobre os componentes musculares e neurais (Douglas et al., 2017; Hody et al., 2019).

As adaptações promovidas pelo treinamento excêntrico têm recebido crescente atenção na literatura científica, especialmente pelos seus efeitos superiores sobre a remodelação estrutural e funcional das fibras musculares. De acordo com (Andrews et al., 2025), esse tipo de estímulo promove maior adição de sarcômeros em série, aumento da rigidez dos componentes elásticos e aprimoramento da arquitetura muscular, resultando em ganhos expressivos de força e resistência ao alongamento. Essas respostas são sustentadas por processos de sinalização celular mediados por vias como a *mammalian target of rapamycin complex 1* (mTORC1) e a *mitogen-activated protein kinase* (MAPK), que coordenam a síntese proteica e a regeneração tecidual. Além disso, (Franchi et al., 2017) já haviam demonstrado que o treinamento excêntrico favorece a hipertrofia longitudinal e a adaptação dos elementos contráteis, destacando-se como uma ferramenta essencial tanto na prevenção quanto na reabilitação de lesões musculares.

Os mecanismos neurais também desempenham papel central nas adaptações decorrentes do treinamento excêntrico. Conforme descrito por (Andrews et al., 2025), esse tipo de estímulo contribui para aprimorar o recrutamento de unidades motoras e otimizar a coativação entre músculos agonistas e antagonistas, refletindo em melhor desempenho e menor risco de lesão. Estudos recentes corroboram esses achados, demonstrando que intervenções excêntricas promovem adaptações neuromusculares associadas à melhora da coordenação e ao aumento da tolerância à carga mecânica (Hickey et al., 2022; Maeo et al., 2014). Essas adaptações, de natureza neural e morfológica, evidenciam a complexa interação entre estímulo mecânico, plasticidade neural e remodelação tecidual.

(Taber et al., 2021b) exploraram os efeitos agudos de diferentes combinações de estratégias de carga concêntrica e excêntrica durante o supino de carga

excêntrica acentuada. Um espectro de cargas excêntricas (100% e 110% de 1RM) e concêntricas (30%, 40%, 50%, 60%, 70% e 80% de 1RM) foram usadas. Os autores relataram que os efeitos da carga excêntrica acentuada dependem da combinação das magnitudes de carga excêntrica e concêntrica, já que a carga excêntrica acentuada com 100% de velocidade concêntrica aumentada em 1RM é maior do que com 110% de 1RM.

(Tøien et al., 2018) avaliaram os efeitos do treinamento de força máxima com ou sem sobrecarga excêntrica sobre o impulso neural eferente, capacidade geradora de força e desempenho funcional. Implicando que um grupo de treinamento realizou ação concêntrica e excêntrica a 90% de 1RM, enquanto o outro grupo de treinamento realizou uma fase concêntrica com 90% 1RM seguida de uma fase excêntrica com 150%. Os autores mostraram que a sobrecarga excêntrica não potencializa os aumentos induzidos pelo treinamento de força na capacidade geradora de força e no impulso neural eferente se o treinamento de força for realizado com alta intensidade e velocidade máxima pretendida na fase concêntrica. Assim, se o objetivo for adaptar o treinamento mais eficaz para melhorias em RFD, força máxima e desempenho funcional, uma sobrecarga excêntrica pode ser evitada. Em vez disso, treinamento de força tradicional é altamente eficaz e pode ser recomendada em populações de pacientes jovens, idosos e frágeis previamente não treinados.

O foco na fase excêntrica durante o exercício supino reto é sustentado por evidências que demonstram uma maior capacidade de produção de força durante ações musculares excêntricas em comparação às concêntricas (Douglas et al., 2017; Enoka, 1996; Franchi et al., 2017), por meio do elevado estresse mecânico imposto ao complexo músculo-tendão, capaz de gerar mais de 40% mais força em contrações excêntricas do que concêntricas (Nuzzo et al., 2023). Essa superioridade mecânica está associada a fatores neurais e estruturais, incluindo maior contribuição dos componentes elásticos passivos, maior eficiência na formação e manutenção das pontes cruzadas e menor custo metabólico relativo (Hody et al., 2019).

No contexto do supino reto, a ênfase na fase excêntrica permite o uso de sobrecargas superiores às da fase concêntrica, potencializando adaptações neuromusculares relacionadas ao aumento da força máxima, à melhoria do controle

motor e à estabilidade articular do complexo do ombro (Suchomel et al., 2019; Taber et al., 2021b). Assim, a incorporação estratégica de estímulos excêntricos no treinamento de supino reto configura-se como uma abordagem eficaz para maximizar o desempenho e promover adaptações funcionais relevantes, especialmente em populações treinadas.

Uma revisão sistemática conduzida por (Suchomel et al., 2019) apresentou uma visão geral de quatro dos principais métodos de treinamento excêntrico: tempo de treino excêntrico, treinamento com volante de inercia, carga excêntrica acentuada e treinamento pliométrico. Os autores relataram que embora possam ocorrer melhorias ao usar múltiplos métodos de treinamento, os praticantes precisam estar atentos ao estresse associado ao volume de treinamento combinado e como as estratégias de manejo da fadiga diferem em comparação com os métodos tradicionais de treinamento para garantir que as adaptações desejadas ocorram.

Embora hoje haja evidências consideráveis sobre a importância de altos níveis de força excêntrica em atividades esportivas, a questão de como o exercício excêntrico deve ser integrado ao treinamento ainda é menos compreendida, incluindo: como limitar o grau de dor muscular e fadiga de início tardio após o treinamento excêntrico, que tipo de treinamento excêntrico deve ser usado com seus atletas em diferentes fases do plano de periodização, e como uma variedade de características do atleta, como a idade, sexo, esportes e histórico de treinamento podem influenciar o que constitui a forma ideal de treinamento excêntrico deles (Harris-Love et al., 2021).

Assim, a incorporação de estímulos excêntricos bem estruturados emerge como um componente indispensável para o aprimoramento do desempenho atlético e para a longevidade funcional dos praticantes de treinamento de força. A aplicação criteriosa desse método, especialmente em populações com necessidades específicas, como os atletas de *Powerlifting* Paralímpico, pode favorecer tanto o desempenho neuromuscular quanto a modulação de marcadores bioquímicos associados ao estresse e à recuperação, representando uma estratégia de grande relevância para o treinamento de força contemporâneo (Andrews et al., 2025; Hody et al., 2019).

O posicionamento *do American College of Sports Medicine* (ACSM) destaca que diferentes combinações dessas variáveis podem ser manipuladas para otimizar adaptações relacionadas à força muscular, hipertrofia e desempenho físico,

respeitando o nível de treinamento e as características individuais dos praticantes. Além disso, evidencia que tanto abordagens tradicionais quanto estratégias mais avançadas podem ser eficazes, desde que fundamentadas em princípios do treinamento esportivo (Currier et al., 2026).

1.5 INDICADORES ESTÁTICOS DA FORÇA

A força real que um músculo pode exercer não é apenas uma função do nível de ativação produzido por um comando voluntário, mas também depende da velocidade com que o músculo muda de comprimento: a chamada "relação força-velocidade" do músculo (Hill A. V., 1970). Em condições isométricas, onde não há variação no comprimento muscular, é possível avaliar de forma direta a capacidade de geração de força, minimizando interferências associadas à velocidade do movimento, o que tem sido amplamente explorado em protocolos contemporâneos de avaliação neuromuscular (Harris-Love et al., 2021). Essa relação constitui um dos pilares da biomecânica muscular e permanece como base teórica para o entendimento do desempenho motor e das adaptações ao treinamento resistido (Enoka, R. M., 2015).

Embora contrações concêntricas forneçam a força propulsora necessária para movimentos como correr, pular, arremessar e levantar, uma estratégia comum de movimento humano é combinar contrações excêntricas e concêntricas em uma sequência conhecida como ciclo de alongamento-encurtamento (Komi, 1984). A inclusão do ciclo de alongamento-encurtamento aparece na maioria dos movimentos sem a necessidade de treinamento especializado.

O sistema nervoso monitora o nível de ativação e o torque gerado pelo músculo, e se este torque for superado pela carga externa, ocorre uma ação excêntrica. A ativação dos motoneurônios que inervam o músculo é independente do tipo de contração (isométrica, concêntrica, excêntrica), e apenas a intensidade da ativação é modulada de acordo com o torque muscular desejado (Enoka, 1996).

Uma razão pela qual o treinamento concêntrico e excêntrico pode produzir efeitos semelhantes em comparação é que o trabalho total precisa ser maior durante o treinamento excêntrico se o nível de intensidade for buscado para ser o mesmo (Tøien et al., 2018). Como a intensidade é um componente chave para melhorias induzidas pelo treinamento de força, uma intensidade maior será mais eficaz

(Heggelund et al., 2013). Isso também pode resultar em uma contribuição excêntrica relativamente maior para a melhoria da força total.

Nesse contexto, os indicadores estáticos da força têm sido amplamente utilizados para avaliar o desempenho neuromuscular, especialmente em populações atléticas. Entre os principais indicadores destacam-se a força isométrica máxima (FIM), a taxa de desenvolvimento de força (TDF) e o tempo até a força isométrica máxima (TFIM). A FIM representa a maior força voluntária que um indivíduo é capaz de produzir em uma contração isométrica, sendo considerada um importante marcador da capacidade neuromuscular (Suchomel et al., 2016). A TDF reflete a capacidade do sistema neuromuscular de gerar força rapidamente, sendo altamente dependente de fatores neurais, como o recrutamento de unidades motoras, a frequência de disparo e a sincronização neural (Maffiuletti et al., 2016). O TFIM fornece informações sobre a rapidez com que o indivíduo atinge seu pico de força, sendo um indicador da eficiência neuromuscular, especialmente quando analisado em conjunto com a taxa de desenvolvimento de força (Andersen & Aagaard, 2006; Maffiuletti et al., 2016).

Esses indicadores estão associados à ativação neural, a rigidez musculotendínea e a arquitetura muscular. Adaptações ao treinamento de força podem promover melhorias nesses parâmetros, especialmente quando há manipulação adequada da intensidade e do tipo de contração (Buckthorpe & Roi, 2017). Embora contrações dinâmicas (concêntricas e excêntricas) sejam fundamentais para o desempenho esportivo, a avaliação isométrica apresenta vantagens metodológicas importantes, como maior reprodutibilidade e sensibilidade para detectar alterações neuromusculares agudas e subagudas (Maffiuletti et al., 2016).

Além disso, no contexto do powerlifting paralímpico, no qual o controle motor e a estabilidade são determinantes para o desempenho, os indicadores estáticos tornam-se particularmente relevantes para o monitoramento do treinamento e da fadiga. O treinamento excêntrico tem sido associado a maiores níveis de força produzida com menor ativação elétrica muscular, o que sugere maior eficiência neuromuscular em determinadas condições (Enoka, 1996). No entanto, esse tipo de estímulo também está relacionado a maiores níveis de estresse mecânico e dano muscular, podendo impactar negativamente a TDF e o tempo de recuperação (Douglas et al., 2017).

Os indicadores estáticos da força apresentam elevada aplicabilidade no monitoramento da fadiga neuromuscular e na interpretação do estado do atleta.

Reduções na FIM e, principalmente, na TDF têm sido associadas a estados de fadiga aguda e residual, refletindo alterações na capacidade de recrutamento neural e na eficiência do sistema neuromuscular (Aagaard et al., 2002, p. 200; Maffiuletti et al., 2016). Nesse sentido, a TDF tem sido considerada mais sensível do que a FIM para detectar alterações precoces no desempenho, especialmente em fases iniciais da contração muscular (Maffiuletti et al., 2016).

O comportamento temporal da força, representado por variáveis como o TFIM, pode fornecer informações complementares sobre a eficiência neuromuscular, particularmente em ações que exigem produção de força rápida (Aagaard et al., 2002). No Powerlifting Paralímpico, onde o tempo de aplicação de força é determinante para o sucesso da tentativa, a capacidade de atingir rapidamente altos níveis de força pode representar um diferencial competitivo (Suchomel et al., 2016).

O uso de avaliações isométricas reduz a variabilidade associada à execução técnica e à velocidade do movimento. Isso fato é relevante no Powerlifting Paralímpico, onde fatores como estabilidade, controle motor e adaptações funcionais influenciam diretamente o desempenho. Nesse sentido, os indicadores estáticos tornam-se ferramentas úteis não apenas para avaliação do desempenho, mas também para o acompanhamento das adaptações ao treinamento (Suchomel et al., 2016).

No treinamento de força, diferentes métodos podem impactar de maneira distinta esses indicadores. Evidências sugerem que o treinamento excêntrico pode promover aumentos expressivos na força máxima, porém frequentemente associado a maiores níveis de dano muscular e fadiga, o que pode resultar em reduções da TDF e aumento no tempo necessário para recuperação neuromuscular (Douglas et al., 2017). Já o treinamento tradicional, tende a promover respostas mais estáveis, com menor perturbação aguda nesses indicadores (Suchomel et al., 2016).

Apesar dos avanços na literatura, ainda são escassos os estudos que investigam de forma integrada os indicadores estáticos da força em associação com outras respostas fisiológicas, como a termorregulação e o estresse oxidativo, especialmente em atletas de Powerlifting Paralímpico. Essa limitação dificulta a compreensão abrangente das respostas ao treinamento de força e corrobora a ecessidade de abordagens concomitante aos aspectos neuromusculares, mecânicos e fisiológicos, como proposto na presente tese.

1.6 INDICADORES DINÂMICOS DA FORÇA

A TDF é inerentemente de grande importância para atletas envolvidos em

esportes que envolvem um tipo explosivo de ação muscular. Assim, adaptações concomitantes no impulso neural eferente e na RFD contrátil podem ser esperadas em resposta ao treinamento de resistência (Aagaard et al., 2002).

Diversos métodos levaram a importantes linhas de investigação na produção de força excêntrica, variação nas estratégias de ativação neuromuscular baseada no modo de ação muscular e as adaptações morfológicas diferenciais do músculo e tendão que resultam de ações crônicas dos músculos excêntricos (Franchi et al., 2017). As ações excêntricas da musculatura esquelética geram produção líquida de força durante o alongamento ativo dos músculos e continuam sendo uma curiosidade científica do desempenho das tarefas (Harris-Love et al., 2021).

Segundo (Enoka, R. M., 2015), a capacidade de gerar força em diferentes velocidades está diretamente relacionada ao tipo de fibra muscular ativada. As fibras do tipo I, de contração lenta e metabólito oxidativo, apresentam tempos de contração que variam entre 90 a 120 milissegundos (ms), são mais resistentes à fadiga e eficientes para ações sustentadas. As fibras do tipo IIa, de contração rápida e metabolismo misto (oxidativo e glicolítico), têm tempos intermediários, em torno de 40 a 60 ms, enquanto as fibras tipo IIx, mais explosivas e dependentes da glicólise anaeróbia, apresentam tempos entre 20 a 40 ms. Essas diferenças determinam a capacidade funcional do músculo em responder a demandas específicas de força, velocidade ou potência.

Na extremidade de altas velocidades da curva força–velocidade, apenas unidades motoras que inervam fibras rápidas conseguem manter níveis elevados de produção de força, enquanto as fibras lentas contribuem de forma limitada. Dessa forma, o desempenho em ações rápidas e potentes, como saltos, arremessos ou movimentos balísticos, depende fundamentalmente do recrutamento eficiente de fibras do tipo II, bem como da capacidade do sistema nervoso central em elevar a frequência de disparo e a sincronização entre unidades motoras (Enoka, R. M., 2015). Além da composição das fibras, fatores neurais como taxa de desenvolvimento de força (RFD), coordenação intermuscular e coativação antagonista exercem influência direta sobre o formato e o deslocamento da curva.

Evidências experimentais indicam que a Curva Força–Velocidade não é fixa, podendo ser modificada por intervenções específicas de treinamento. Protocolos que enfatizam ações rápidas, esforços máximos ou contrações excêntricas são capazes de promover deslocamentos da curva, permitindo maior produção de força em velocidades elevadas ou aumento da potência mecânica. Essas adaptações decorrem tanto de modificações estruturais, como alterações na arquitetura

muscular e na rigidez dos elementos elásticos quanto de ajustes neurais relacionados ao recrutamento e à frequência de disparo das unidades motoras (Douglas et al., 2017; Enoka, R. M., 2015; Hody et al., 2019).

Nesse contexto, a Curva Força–Velocidade configura-se como uma ferramenta fisiológica e biomecânica essencial para compreender o comportamento muscular frente a diferentes exigências mecânicas. Sua interpretação envolve a integração de fatores estruturais (tipos e arquitetura das fibras musculares), neurais (recrutamento, sincronização e frequência de ativação) e metodológicos (tipo, intensidade e velocidade do treinamento), sendo particularmente relevante para o entendimento do desempenho em modalidades de força máxima, como o Powerlifting Paralímpico.

O experimento clássico conduzido por (Hill, A.V., 1938) permitiu a formulação da equação matemática que descreve essa relação:

$$(F + a) \cdot (V + b) = (F_0 + a) \cdot b$$

Onde F representa a força exercida (carga), V a velocidade de encurtamento, F_0 a força isométrica máxima, e a e b são constantes específicas das propriedades contráteis do músculo.

A interpretação dessa equação está fortemente ligada ao mecanismo das pontes cruzadas entre actina e miosina: em baixas velocidades, há tempo suficiente para um maior número de pontes cruzadas formarem-se e gerarem força; em altas velocidades, menos pontes conseguem se formar antes da separação, reduzindo a força total produzida. Assim, a equação de Hill traduz a dinâmica molecular do ciclo actina-miosina em um modelo macroscópico de desempenho muscular, sendo essencial para entender o comportamento da musculatura esquelética em resposta a diferentes cargas e velocidades.

Em um dos primeiros estudos sobre esse tema, (González-Badillo & Sánchez-Medina, 2010) afirmaram que existe uma relação inseparável entre carga relativa e velocidade média que nos permite usar uma para estimar a outra com grande precisão e que as velocidades alcançadas com cada % 1RM podem diferir muito ligeiramente devido às diferenças na velocidade de 1RM, não podendo ser totalmente compreendida ou interpretada uma sem a outra.

Essa conclusão foi obtida analisando as correlações entre valores distintos de 1RM e a velocidade da barra durante o exercício de supino, onde independentemente do nível de força e da fase de treinamento dos indivíduos, o R permaneceram estáveis, com valor total igual a 0,98.

Um dos principais problemas enfrentados pelos treinadores de força e condicionamento é em razão da quantificação e monitoramento da carga de treinamento real realizada pelos atletas para maximizar o desempenho (González-Badillo & Sánchez-Medina, 2010). Diversas variáveis agudas de treinamento foram identificadas para o planejamento de programas de treinamento de resistência como tipo e ordem do exercício, intensidade ou carga, número de repetições e séries e descansos entre as séries (Kraemer & Ratamess, 2004).

Expressar a intensidade do treino como uma porcentagem do máximo de uma repetição (1RM) é o método mais comum usado para ajustar a intensidade por praticantes de força (Suchomel et al., 2021). A estimativa dos percentuais de intensidade adotados durantes as sessões de treinamento de força são baseadas em zonas de repetições (Baechle & Earle, 2008):

Repetições	**% 1RM**
1	100
2	95
3	93
4	90
5	87
6	85
7	83
8	80
9	77
10	75
11	70
12	67
15	65

O teste de 1RM tradicional na prescrição do treinamento de força, apresenta limitações práticas e metodológicas, sendo cada vez menos compatível com o esporte moderno; além disso, variações na velocidade de movimento em diferentes cargas permitem monitorar a força com maior sensibilidade do que o próprio 1RM (Loturco et al., 2026). A manipulação dessas variáveis molda a magnitude e o tipo de respostas fisiológicas e, em última análise, as adaptações ao treinamento de força (Bird et al., 2005).

Nesse sentido, prescrever e monitorar a carga de treinamento de acordo com a velocidade, em vez de porcentagens de 1RM apresenta uma alternativa segura, já que são altamente modificáveis diariamente. Quanto maior a velocidade alcançada contra uma determinada carga, maior a intensidade, e isso influenciará o efeito de treinamento. Assim, a velocidade de movimento é um ingrediente-chave da intensidade do treinamento.

Outro método de monitoramento do treinamento de força é a medição da velocidade de movimento, chamada de treinamento baseado em velocidade (VBT). A VBT requer o uso de equipamentos (transdutor de posição linear, unidade de medição inercial, etc.) que mensurar e/ou calculem métricas como deslocamento e velocidade da barra, tendo como principal indicador a velocidade média propulsiva (Suchomel et al., 2021).

Com essa abordagem de treinamento, a prescrição do exercício se baseia na velocidade média da primeira repetição e na perda máxima percentual de velocidade a ser permitida em cada conjunto (González-Badillo et al., 2011). Quando esse limite percentual de perda for ultrapassado, o conjunto deve ser terminado.

Apenas aquelas repetições cuja velocidade concêntrica média não é maior que 0,20 m/s devem ser consideradas como repetições máximas verdadeiras. À medida que V1RM excede esse valor, as velocidades médias alcançadas com cada % 1RM e as próprias cargas relativas se desviariam de seus valores reais. Isso significa que, quando o V1RM não é realmente medido, como ocorre com frequência, os valores correspondentes da velocidade média a cada 1RM, assim

como essas próprias porcentagens, podem facilmente diferir dos valores reais (González-Badillo et al., 2011).

Segundo (Sanchez-Medina et al., 2010), a velocidade de movimento, expressa como velocidade propulsiva média (MPV), pode ser considerada a variável mais estável para avaliação da força muscular em condições isoinerciais e a relação com o percentual de 1RM está descrito na tabela a seguir:

Carga (%1RM)	VMP (m/s)
30	1.31
35	1.22
40	1.13
45	1.04
50	0.95
55	0.87
60	0.78
65	0.70
70	0.62
75	0.55
80	0.47
85	0.39
90	0.32
95	0.25
100	0.18

Outra relação direta com a velocidade nos modelos de treinamento é a resposta mecânica e metabólica a diferentes repetições, o que apoia o uso dessa variável para quantificar a fadiga muscular durante o exercício através do índice de esforço que provavelmente envolverá um estímulo de treinamento diferente e, com isso, adaptações neuromusculares diferentes (Rodríguez-Rosell et al., 2018).

No contexto do monitoramento esportivo, a carga de treinamento é o estímulo central aplicado durante a preparação e competição, servindo como o dado primário para o controle de desempenho. Esse conceito é subdividido em carga externa, que quantifica o trabalho físico objetivo (como peso levantado ou velocidade de execução), e carga interna, que reflete as adaptações fisiológicas e as percepções subjetivas do atleta diante do esforço realizado.

Embora a carga interna reflita o custo agudo do treinamento, ela deve ser distinguida dos indicadores do estado do atleta (por exemplo, fadiga ou prontidão), que descrevem o estado atual do atleta. Tanto as cargas internas quanto externas

fornecem *insights* complementares: a carga externa reflete a dose de treinamento, enquanto a carga interna captura a resposta a essa dose (Rebelo et al., 2026).

1.6 ESTRESSE OXIDATIVO E EXERCÍCIO

No final da década de 1970, (Dillard et al., 1978) descobriram que exercícios de resistência aumentaram os níveis de um marcador de peroxidação lipídica (pentano vencido) no ar coletado em um espirômetro, e que a suplementação com vitamina E reduziu o aumento induzido pelo exercício na produção de pentano. Posteriormente, (Brady et al., 1979) relataram um aumento nas substâncias reativas do ácido tiobarbitúrico (TBARS), um indicador de peroxidação lipídica, tanto no fígado quanto no músculo de ratos, como resposta ao estresse de natação. Neste estudo, esse aumento no dano oxidativo dos músculos esqueléticos não foi afetado pelo E da dieta ou pelo selênio dietético. (Davies et al., 1982) mostraram pela primeira vez, em um estudo *in vivo*, um aumento de duas a três vezes no conteúdo de radicais livres do músculo esquelético em ratos após exercícios até a exaustão. Além disso, (Salminen & Vihko, 1983) relataram que um protocolo de treinamento de curto prazo (três semanas) foi suficiente para reduzir a suscetibilidade do músculo esquelético do camundongo à peroxidação lipídica usando uma abordagem *in vitro*.

(Quintanilha & Packer, 1983) mostraram pela primeira que os sistemas antioxidantes endógenos tanto do músculo cardíaco quanto do esquelético são plásticos e se adaptam em resposta ao treinamento de exercícios. Logo depois, o termo estresse oxidativo foi definido pela primeira vez como uma perturbação no equilíbrio pró-oxidante/antioxidante em favor do primeiro (Sies & Cadenas, 1985).

A fisiologia do exercício frequentemente adota uma abordagem reducionista para explicar como o desempenho pode ser direcionado aos componentes individuais do corpo humano, como capacidade oxidativa muscular, débito cardíaco ou ativação neuromuscular (Kontro et al., 2026). Já a fisiologia contemporânea reconhece a integração de múltiplos subsistemas interagentes, incluindo processos energéticos, cardiovasculares, neuromusculares e de sinalização endócrina, cada um dos quais contribui para a resposta adaptativa (Inglis et al., 2024).

Os biomarcadores redox são moléculas sensíveis a redox que respondem ao estresse oxidativo em sistemas biológicos e podem ser classificados em diferentes categorias que incluem a medição da produção de oxidantes, níveis de antioxidantes, produtos de oxidação e o equilíbrio antioxidante/pró-oxidante (Gomez-Cabrera et al., 2021).

Entre os principais alvos sensíveis ao redox que apoiam funções biológicas, pode-se destacar um fator de transcrição responsável pela resposta antioxidante (Nrf2); as quinases proteicas ativadas por Mitogênio (MAPKs) e as quinases proteicas ativadas por AMP (AMPK) envolvidas na autofagia e biogênese mitocondrial; um mediador da resposta inflamatória (NF-κB) e o fator induzível de hipóxia (HIF); a enzima glicealdeído-3-fosfato desidrogenase (GAPDH), que está relacionada a adaptações metabólicas; o fator de transcrição nuclear Forkhead Box Protein O (FOXO), envolvido na adaptação ao estresse; um fator de transcrição nuclear que regula a apoptose (p53), e as Proteínas de Desacoplamento (UCPs), que regulam a energética das mitocôndrias (Sies & Jones, 2020).

As principais adaptações em que as espécies reativas de oxigênio e nitrogênio estão envolvidas durante o exercício são: aumento da massa mitocondrial, defesa aprimorada contra antioxidantes e hipertrofia das miofibras. Eles afetam a função das proteínas, a atividade enzimática, a transcrição gênica e a integridade das membranas e do genoma (Gomez-Cabrera et al., 2021).

Exercícios regulares são benéficos para nossa saúde, no entanto, exercícios exaustivos podem resultar em efeitos prejudiciais como danos musculares, inflamação e estresse oxidativo (EO). Exercícios intensos aumentam os índices bioquímicos de estresse oxidativo medidos tanto de forma sistêmica quanto no músculo de trabalho (Reid, 2008). Embora a literatura evidencie consistentemente a elevação do estresse oxidativo associado ao esforço físico, os mecanismos redox precisos que governam a sinalização e as adaptações fisiológicas subsequentes permanecem inconclusivos, persistindo uma lacuna na síntese sistemática sobre como diferentes parâmetros de exercício modulam a produção de espécies reativas de oxigênio (EROs) (F. He et al., 2016).

O treinamento físico sistematizado otimiza o desempenho atlético ao modular a intensidade e a duração para induzir adaptações fisiológicas dose-dependentes, as quais são mediadas por alterações agudas nas concentrações de metabólitos intramusculares, incluindo o difosfato de adenosina (ADP), fosfato inorgânico (Pi), lactato e prótons (H+) em resposta à demanda energética imposta (Inglis et al., 2024; Kontro et al., 2026). As bases das nossas adaptações ao treinamento físico são provenientes do resultado do acúmulo de exercícios. O organismo se adapta alterações em longo prazo que ocorrem em nosso corpo como consequência do treinamento.

O estresse oxidativo é definido como um desequilíbrio entre a produção de EROs e a capacidade dos sistemas antioxidantes em neutralizá-las,

desempenhando papel central em diversos processos fisiológicos e patológicos no organismo humano (Z. He et al., 2021). No exercício físico, a geração de ROS aumenta de forma aguda devido à elevação do consumo de oxigênio, à ativação mitocondrial e a processos inflamatórios associados à contração muscular repetida (Davies et al., 1982). Inicialmente, essas espécies foram associadas predominantemente a danos celulares, incluindo peroxidação lipídica, oxidação de proteínas e alterações no DNA (Dillard et al., 1978).

Entretanto, evidências mais recentes indicam que as EROs exercem uma dupla função no músculo esquelético, atuando tanto como agentes potencialmente deletérios quanto como importantes mediadores de sinalização celular envolvidos em adaptações induzidas pelo exercício (Powers et al., 2020). Em níveis moderados, as EROs participam da regulação da biogênese mitocondrial, da ativação de fatores de transcrição redox-sensíveis e da adaptação funcional do músculo esquelético ao treinamento físico (Wang et al., 2021). Dessa forma, o estresse oxidativo induzido pelo exercício não deve ser interpretado exclusivamente como prejudicial, mas como um componente necessário para o processo adaptativo, desde que adequadamente controlado (Powers et al., 2020).

O tecido muscular esquelético caracteriza-se por uma notável plasticidade fenotípica em resposta a estímulos contráteis, nos quais a elevada demanda metabólica promove uma produção robusta das EROs; essas moléculas, embora instáveis devido à presença de elétrons desemparelhados, atuam como mensageiros secundários cruciais na orquestração de vias de sinalização redox-sensíveis que medeiam as adaptações musculares crônicas ao treinamento (Steinbacher & Eckl, 2015). Uma sessão de exercício exaustivo demonstrou causar danos oxidativos em indivíduos não treinadas, enquanto em treinados, nenhum efeito é observado devido ao aumento da resistência dessas pessoas ao estresse oxidativo (Reid, 2008).

No treinamento, o tipo, a intensidade e o volume do exercício físico influenciam diretamente a magnitude da resposta oxidativa, sendo que exercícios de alta intensidade, como os realizados por levantadores de peso, tendem a induzir maior produção das EROs. Além disso, a resposta oxidativa está intimamente relacionada à inflamação aguda pós-exercício, uma vez que células inflamatórias recrutadas para o tecido muscular também contribuem para o aumento local de espécies reativas (Magherini et al., 2019). Nesse sentido, o estresse oxidativo e a inflamação atuam de forma integrada, modulando tanto o dano muscular quanto os mecanismos de regeneração e adaptação (Wang et al., 2021).

A resposta do músculo esquelético a exercícios excêntricos não habituados tem sido amplamente estudada, mas é incompletamente compreendida (Hyldahl & Hubal, 2014). As ações dos músculos excêntricos são a principal fonte de dano muscular durante o exercício. Sarcoplasma, sarcolema e a matriz extracelular da fibra muscular podem sofrer alterações estruturais após uma única sessão de exercício prejudicial. A variação dos níveis de CK (Creatina Quinase), LDH (Lactato Desidrogenase), AST (Aspartato Aminotransferase) e ALT (Alanina Aminotransferase) pré e pós-exercício são os marcadores mais úteis de lesão muscular (Brancaccio et al., 2010).

As três isoenzimas citoplasmáticas de CK, CK-MM, CK-MB, CK-BB, são aumentadas após exercícios prolongados e intensos, fazendo com que o nível total de CK seja até quatro vezes superior ao seu valor normal. Os níveis totais de LDH também aumentam após exercícios excêntricos (até duas vezes). Embora os valores séricos de alanina aminotransferase (ALT) e aspartato aminotransferase (AST) e a razão AST/ALT sejam usados para diagnosticar doença hepática crônica, a atividade do AST também aumenta significativamente após esforço muscular (Brancaccio et al., 2010). Os níveis de alguns metabólitos, como fragmentos de titina na urina, elevam em resposta a danos musculares induzidos por exercícios excêntricos (Kanda et al., 2017).

O exercício excêntrico, caracterizado pela produção de força durante o alongamento ativo do músculo, apresenta particular relevância na discussão sobre estresse oxidativo devido ao seu elevado potencial de indução de microlesões estruturais (Davies et al., 1982). Esse tipo de contração está associado a maior estresse mecânico sobre os sarcômeros, o que favorece a disfunção mitocondrial transitória e o aumento da produção de ROS no período pós-exercício (Wang et al., 2021). Consequentemente, exercícios excêntricos tendem a gerar respostas oxidativas mais pronunciadas quando comparados a exercícios concêntricos ou isométricos (Powers et al., 2020).

Apesar disso, a exposição repetida e controlada ao exercício excêntrico promove adaptações antioxidantes importantes, incluindo o aumento da atividade de enzimas como superóxido dismutase (SOD), catalase (CAT) e glutationa peroxidase (GPx) (Powers et al., 2020). Essas adaptações contribuem para a redução do estresse oxidativo em sessões subsequentes, fenômeno conhecido como “efeito protetor repetido” (Magherini et al., 2019). Assim, o exercício excêntrico, quando adequadamente prescrito, pode atuar como estímulo eficaz para o fortalecimento da capacidade antioxidante e para a melhora da função muscular, reforçando o caráter

adaptativo e benéfico do estresse oxidativo induzido pelo exercício físico (Wang et al., 2021).

Embora os sistemas antioxidantes endógenos sejam modulados pelo esforço físico, a administração de compostos exógenos (vitaminas C, E e carotenoides) via suplementação tem sido questionada quanto à sua interferência nas respostas adaptativas (Steinbacher & Eckl, 2015). A indução de enzimas de defesa endógena, incluindo a superóxido dismutase manganês-dependente (Mn-SOD), zinco-dependente (Zn-SOD) e a glutationa peroxidase (GPX) é dependente do estresse oxidativo transitório gerado pelo exercício, sendo este processo adaptativo essencial para a homeostase metabólica e saúde sistêmica bloqueado pela ingestão crônica de antioxidantes exógenos (Ristow et al., 2009; Steinbacher & Eckl, 2015).

Há grande interesse da pesquisa voltada ao esporte na identificação de biomarcadores para avaliar saúde, desempenho, recuperação durante o treinamento de exercícios e sobre treinamento (Lee et al., 2017). Entre os diferentes conjuntos de biomarcadores que podem ser determinados na população esportiva para realizar sua avaliação, podemos incluir o seguinte: (i) nutrição e saúde metabólica (macronutrientes e micronutrientes metabolismo), (ii) status de hidratação (osmolaridade plasmática e sódio, sede, creatinina), (iii) status muscular (IGF-1, testosterona, deshidroepiandrosterona, aminoácidos, marcadores de dano muscular), (iv) parâmetros de resistência (ferritina, transferrina, hemoglobina), (v) status de lesão e risco (proteína B que liga cálcio S100, densidade mineral óssea), e (vi) inflamação (interleucinas, proteína quimioatraente de monócitos, proteína C-reativa) (Gomez-Cabrera et al., 2021).

Em suma, o estresse oxidativo induzido pelo exercício físico representa uma resposta fisiológica necessária para adaptações celulares, e seu caráter potencialmente prejudicial ou benéfico depende do balanceamento entre produção de ROS e capacidade antioxidante. No exercício excêntrico, esse balanceamento é particularmente desafiador devido ao elevado estresse mecânico inicial, mas também altamente eficaz em promover adaptações antioxidantes quando aplicado de forma progressiva e controlada (Powers et al., 2020; Wang et al., 2021).

1.7 QUESTÕES EM ESTUDO

As problemáticas que a presente investigação se propõe a esclarecer são as seguintes:

Quais os efeitos de diferentes métodos de treinamento de força (tradicional e excêntrico) sobre indicadores de força estática (força isométrica máxima e tempo

para alcançar a força isométrica máxima), ativação muscular e temperatura da pele em atletas de *powerlifting* paralímpico?

Quais os efeitos agudos do treino tradicional e excêntrico na temperatura da pele e desempenho neuromuscular em atletas de *powerlifting* paralímpico?

Quais os efeitos do treinamento excêntrico na modulação do estresse oxidativo e na melhoria da performance em atletas de *powerlifting* paralímpico?

1.8 ORGANIZAÇÃO DA TESE

Considerando o volume de dados coletados, o número expressivo de variáveis analisadas e, principalmente, a heterogeneidade das questões previamente delineadas, decidiu-se estruturar a presente tese em três estudos distintos e complementares, possibilitando responder de forma abrangente às problemáticas propostas na ordem a seguir:

O estudo 1: **AVALIAÇÃO DA FORÇA, TEMPERATURA DA PELE E ATIVAÇÃO MUSCULAR NO TREINAMENTO TRADICIONAL E EXCÊNTRICO EM ATLETAS DE LEVANTAMENTO DE PESO PARALÍMPICO;**

O estudo 2: **EFEITOS AGUDOS DO TREINAMENTO EXCÊNTRICO VERSUS O TREINAMENTO TRADICIONAL NA FORÇA ISOMÉTRICA, POTÊNCIA E TERMORREGULAÇÃO EM ATLETAS PARALÍMPICOS DE LEVANTAMENTO DE PESO;**

O estudo 3: **EFEITO DO TREINAMENTO EXCÊNTRICO NA MODULAÇÃO DO ESTRESSE OXIDATIVO E NA MELHORA DO DESEMPENHO EM ATLETAS PARALÍMPICOS DE LEVANTAMENTO DE PESO.**

Dessa forma, o segundo capítulo apresenta uma revisão dos estudos já realizados na área, organizada segundo a estrutura convencional dos artigos científicos, contemplando as seções de Resumo, Introdução, Metodologia, Resultados, Discussão e Conclusões.

Por fim, no capítulo final desta Tese são expostas as conclusões gerais, alinhadas às questões centrais da investigação, bem como as potenciais implicações práticas e as perspectivas para futuros estudos.

1.9 OBJETIVOS

Objetivo geral:

Investigar os efeitos agudos e subagudos do treinamento de força tradicional e excêntrico sobre respostas neuromusculares, termorregulatórios e oxidativas em atletas de powerlifting paralímpico.

Objetivos específicos:

OBJETIVO 1: Avaliar os efeitos de diferentes métodos de treinamento de força (tradicional e excêntrico) sobre indicadores de força estática (força isométrica máxima e tempo para alcançar a força isométrica máxima), ativação muscular e temperatura da pele em atletas de *Powerlifting* Paralímpico.

OBJETIVO 2: Analisar os efeitos agudos de diferentes métodos de treinamento de força sobre a força isométrica máxima, a temperatura da pele, a velocidade máxima, a variabilidade da velocidade e a potência mecânica em atletas de *Powerlifting* Paralímpico.

OBJETIVO 3: Avaliar os efeitos dos métodos de treinamento tradicional e excêntrico sobre biomarcadores de estresse oxidativo e indicadores de desempenho físico em atletas de *Powerlifting* Paralímpico.

2 ESTUDOS REALIZADOS

ARTIGO 1

AVALIAÇÃO DA FORÇA, TEMPERATURA DA PELE E ATIVAÇÃO MUSCULAR NO TREINAMENTO TRADICIONAL E EXCÊNTRICO EM ATLETAS DE LEVANTAMENTO DE PESO PARALÍMPICO.

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Evaluation of strength, skin temperature and muscle activation in traditional and eccentric training in Paralympic Powerlifting athletes

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Paralympic Powerlifting (PP) is a maximum strength modality, where male athletes demonstrated greater relative and absolute strength compared to conventional powerlifting. This study aimed to assess the acute effects of traditional training (TT) and eccentric training (ET) methods on Maximum Isometric Strength (MIF), Time to Maximum Isometric Force (Time), Muscle Activation (sEMG), and Skin Temperature (Thermo) in twelve male PP athletes (mean age 30.25 ± 8.13; body weight 72.36 ± 18.47). The training consisted of 5 sets of 5 repetitions (5 × 5), with 80% 1RM in the TT method and in the ET 80% was adopted in the concentric phase and 110% in the eccentric phase, adopting a minimum rest of 3 min between sets and the cadence used was approximately 2 s in the eccentric phase and 1 s in the concentric phase for the ET and 1 s in each phase for the TT. Athletes competing nationally and internationally underwent Thermo, Time, and MIF assessments during TT (80%-1RM for both concentric and eccentric phases) and ET (80%-1RM concentric and 110%-1RM eccentric) at pre-training, post-training, 24 h, and 48 h. sEMG was evaluated in the clavicular portion of the pectoralis major (PMCP), sternal portion of the pectoralis major (PMSP), anterior Deltoid (AD), and Triceps Brachii (BT) during the final series (5 sets of 5 repetitions) of a training session. Athletes exhibited thermal differences in the PMCP muscle at 24 h between TT and ET ($p = 0.020$); Also, after the first 24 h, the AD showed differences between ET and TT ($p = 0.016$) and BT demonstrated differences between ET and TT ($p = 0.028$). The sEMG showed no significant differences between TT and ET ($p > 0.05$). The MIF displayed differences after 48 h between TT and ET ($p = 0.004$). The time showed no significant difference between TT and ET ($p > 0.05$). In conclusion, muscles involved in the bench press exhibited a significant increase in skin temperature with the ET method compared to TT, suggesting greater muscular fatigue. Furthermore, a higher MIF production was observed after the application of the TT in relation to ET, 48 h after training. In the ET, a lower MIF was observed than in the TT, indicating greater fatigue in this type of training.

Keywords Paralympic Powerlifting, Muscle strength, Strength training, Surface electromyography, Thermography

Abbreviations

1RM	1 Repetition maximum
AD	Anterior deltoid
BT	Brachii triceps
CP	Conventional powerlifting
TT	Traditional training
ET	Eccentric training
MIF	Maximum isometric force
PP	Paralympic Powerlifting
PMCP	Pectoralis major clavicular portion
PMSP	Pectoralis major sternal portion
sEMG	Surface electromyography
Therm	Skin temperature

Time	Time until maximum isometric force
WPPA	World para powerlifting
MVIC	Maximum voluntary isometric contraction
RMS	Mean square

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Paralympic Powerlifting (PP) is a muscular strength modality, divided by body weight category, adapted from Conventional Powerlifting (CP), in which the athlete only performs the bench press movement[1]. This movement is done with the lower limbs extended over the bench and can be fixed by straps for eligible deficiencies[1]. Paralympic world record holders demonstrated greater strength (relative and absolute) when compared to conventional ones in six of the eight weight categories for men. Hence, the results of Paralympic athletes were better, presenting greater strength when compared to conventional athletes[2]. The mechanisms underlying the superior strength of Paralympic powerlifting (PP) athletes compared to conventional powerlifting (PC) athletes have not yet been fully elucidated. Data indicate that PP athletes outperform PC athletes in six out of eight body weight categories[3], although the biomechanical and physiological bases of this performance remain unclear. Resende et al.[4] investigated the effects of warm-up in Paralympic athletes and found that, even in the absence of prior warm-up, these individuals exhibited strength levels comparable to those recorded after structured warm-up. The authors suggested that the continuous use of wheelchairs or crutches as a means of locomotion imposes a constant demand on the upper limb musculature, with movement patterns partially analogous to the bench press, acting as a natural warm-up and enhancing neuromuscular readiness for the sport. Thus, the greater daily functional demand on the involved muscles, associated with the aforementioned modes of locomotion, may promote specific neuromuscular adaptations in PP athletes, contributing to superior strength gains compared to PC athletes.

Although the execution of PP is similar to that of CP, there are possible disparities between the training methods used by the athletes[5]. These muscle strength training, used in the preparation of CP and PP, have been shown to be effective in improving performance in competition[5,6]. The training model used plays an important role in periodization. Among the most researched methods for gaining strength, the traditional training method (TT)[7,8] and the eccentric training method (ET)[9,10]. The TT model consist of 1 to 5 repetitions with a heavy load regimen that normally increases strength[11] (80% to 100% of 1 Repetition Maximum (1RM)). However, the magnitude of the eccentric load tends to influence performance responses[10]. Although heavy loads are necessary to achieve maximal gains in isotonic strength, lighter loads also promote substantial increases in this outcome[12]. In the same direction, it was observed that eccentric training would improve muscle mechanical function and provide morphological and architectural adaptations of the muscle–tendon unit. Thus, eccentric loads would be superior to traditional training in terms of strength, power and speed[13].

In the context of Paralympic powerlifting, the choice of training methods is pivotal for athletic performance. The TT, emphasizing concentric contraction, has demonstrated benefits in enhancing muscle strength and power[11]. Conversely, the ET, focusing on the muscle lengthening phase, has proven effective in promoting strength gains, particularly in athletic populations[14]. Given the specificity and complexity of the bench press in Paralympic Powerlifting, leveraging different training methods may yield advantages, optimizing strength gains. Given the absence of a consensus on the most effective training method for athlete preparation, this study is aimed to evaluate the effects of different strength training methods (traditional and eccentric) on static strength indicators (maximum isometric force and time to maximum isometric force), muscle activation, and skin temperature in Paralympic Powerlifting. Our hypotheses were that eccentric training would promote higher skin temperature (I), lower static strength indicators (II), and greater muscle activation than traditional training (III).

Methods

The studied population was made up of Paralympic Weightlifting athletes from the Federal University of Sergipe—Brazil. At the beginning of the training season, the athletes were invited to participate in a meeting, where they explained: the research, the evaluations, the expected benefits, the ethical considerations and any doubts that may exist.

Inclusion criteria required athletes to provide supporting documentation confirming their classification in the competition. To be eligible, athletes needed to be in the top ten in their respective categories, have at least 1

year of competitive experience, have participated in at least one national-level competition in the previous year and commit to participating in the study. Exclusion criteria included refusal to participate and the presence of motor limitations or comorbidities that prevented involvement in the planned evaluations. All pre-selected individuals were submitted to anamnesis to determine their characteristics.

The assessments were carried out over 3 weeks to assess the acute effects of each training method. During the initial week, a familiarization session was held, including collecting the athlete's weight and performing the 1RM test. In the second and 3rd weeks, data collection took place between 9 am and 12 pm, maintaining a room temperature of 25 °C, according to the availability of the subjects. Measurement of Maximum Isometric Force (MIF), Time until Maximum Isometric Force (Time), Skin Temperature (Thermo) and Muscle Activation (sEMG) were acquired for traditional and eccentric training methods, during a single exercise session training. The athletes demonstrated proficiency in training at intensities greater than 80%, employing a variety of training methods in their annual preparations.

During the TT method, a fixed overload of 80% of 1RM was used in the concentric and eccentric phases throughout the movement, as described by Austin and Mann[7]. For the ET method, concentric overload of 80% of 1RM and eccentric overload of 110% of 1RM were used, as described by Taber et al.[10], where in this method a system was adapted for the end of the eccentric phase of the movement. The intervention consisted of 5 sets of 5 repetitions (5X5), with a minimum rest between sets of 3 min and an approximate cadence of 1 s in the concentric phase and 2 s in the eccentric phase. As the weight touched the ground and an additional load of 30% was removed from the bar, thus remaining 80% for the concentric phase of the movement. During training sessions, athletes received verbal encouragement to perform their maximum effort. The sEMG was performed in the last series of each training method. The Thermo, MIF and Time were performed moments before, after, 24 h and 48 h of the procedure, as shown in Table 1.

Sample

In the first stage, individuals received the guidelines relevant to the study and fully complied with the ethical guidelines established in Resolution 466/12 of the National Health Council, which regulates standards for carrying out research on human beings. When agreeing to participate, they signed the Free and Informed Consent Form, approved by the Research Ethics Committee of the Federal University of Sergipe—CAAE: 2,637,882, according to resolution 466/2012 of the National Research Ethics Committee, of the National Health Council, in accordance with the Declaration of Helsinki, guaranteeing the protection of the rights, well-being and dignity of research participants.

Instruments and procedures

To collect body mass, the athletes remained seated on the Micheletti electronic wheelchair scale (Mic Wheelchair Model) of the digital electronic platform type (Micheletti, São Paulo, Brazil), which has a maximum capacity of 300 kg. For the bench press exercise: a bench, bar and powerlifting bench press clip were used from official competitions homologated by the WPPO (Eleiko Sport AB, Halmstad, Sweden)[1].

Maximum load determination

To determine the load, the 1 Repetition Maximum (1RM) test was performed on the bench press, using official equipment, where each athlete used a load to perform only one repetition, with an increase or decrease of 2.4 to 2.5% of the load until reaching 1RM, with an interval of 3 to 5 min for recovery between sets[4].

At the beginning of each test day, the athletes performed a prior warm-up for the muscles involved in the movement with three sets of 10 to 20 repetitions followed by a specific warm-up on the bench press with 30% of the load for 1RM with 10 slow repetitions followed by 10 fast repetitions[15].

Maximal isometric force (MIF) and time until maximal isometric force (Time)

Measurements of maximum isometric force (MIF) and time until maximum isometric force were determined by a Chronojump load cell (Chronojump, BoscoSystem, Barcelona, Spain) Mendonça[16], with a capacity of 500 kg,

Weeks		Day 1	Day 2	Day 3	Other days
Week 1 (Familiarization) 1RM, MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				
Week 2 (Tradicional Training) MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				
Week 3 (Eccentric Training) MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				

Table 1. Experimental drawing—Weekly test schedule. 1RM, One Repetition Maximum; MIF, maximum isometric force; Time, time until maximum isometric force; Thermo, Temperature skin; sEMG, Muscle activation. The tests were carried out using the bench press exercise a homologated by the WPPO[1].

output impedance of 350 ± 3Ω, insulation resistance greater than 2000 cc, input impedance 365 ± 5 Ω, 24-bit analog to digital converter, 80 Hz. Spider HMS Simond carabiners (Simmond, Chamonix, France) were used to fix the equipment on the bench, with breaking load of 21 KN, (UIAA). To fix the load cell to the bench, a steel chain with a breaking load of 2300 kg was used. A perpendicular distance between the load cell and the center of the bench was used as a reference[17,18].

Maximum isometric strength (MIF) and Time until Maximal Isometric Force (Time), was determined by the maximum strength of the upper limbs, and an elbow angle close to 90° was maintained, and at a distance of 15 cm from the bar to the chest. Athletes were instructed to make a single maximum movement (as fast as possible). The fatigue index (FI) was determined in the same way as the MIF, where the athletes maintained the maximum contraction for 5.0 s[19].

The MIF was measured by the maximum force generated by the muscles of the upper limbs during the bench press exercise[1]. The MIF is determined in Newtons (N) by the formula N = (M) × (C), where M = mass in kg and C = 9.80665, measured between the load cell cable attachment point and the bench press. For the isometric test, the elbows were positioned at an angle close to 90°, and the angle was checked using a pendulum fleximeter model FL6010 (Sanny, São Bernardo do Campo, Brazil). The athletes were instructed to perform a maximum movement, seeking to extend their elbows with maximum speed, to evaluate the MIF. The athletes had to maintain the maximum contraction for 5 s to evaluate the time until MIF[17,18].

Surface electromyography (sEMG)

The electromyographic signals were captured using simple electrodes (MAXICOR—Shanghai Intco Electrode Manufacturing Co Ltd, China) fixed to the skin after shaving and cleaning it with alcohol. The electrodes (11 mm contact diameter and 2 cm center-to-center distance) were positioned in the arrangement of the muscle fibers, two centimeters from the center, at the point of greatest muscular area of the pectoralis major muscles, sternal and clavicular portions, anterior deltoid and long head triceps brachii, with the reference electrode fixed to the olecranon, as recommended by SENIAM (Surface Electro Myo Graphy for the Non-Invasive Assessment of Muscles)[20].

The equipment used for recording and analyzing muscle biopotentials was a MIOTEC electromyograph with 8 channels (MIOTEC, Porto Alegre, RS, Brazil). Data were high-pass filtered with a frequency of 20–500 Hz and a notch of 60 Hz. The calculation of the signal amplitude was performed using the root mean square (RMS), with a window of 100 RMS, with normalization by percentage of maximum voluntary isometric contraction (MVIC), considering the beginning and end of the movement.

The signal normalization was performed before the test in each target muscle, with the determination of MVIC through the execution of 1RM isometric bench press, lasting 6 s. The MVIC values obtained were recorded in the electromyography software and used for normalization[6,15].

Thermography (Thermo)

To collect the thermographic image, a room was prepared with artificial lighting, temperature controlled by air conditioning and hygrometer (HM-01; HIGHMED, USA), with a temperature of around 24 °C and relative humidity of around 50%[5,21].

To obtain the thermograms, the athletes remained seated, did not make sudden movements and were instructed not to perform vigorous physical activity in the last 24 h, not to consume alcohol or caffeine and not to use any type of cream or lotion on the skin up to 6 h before evaluation[22]. The images were obtained with a thermal camera (Seek Thermal Compact Pro, Moscow, Russia) (Fig. 1), with a resolution of 320 × 240 pixels and a temperature range of − 4 to 330 °C, at a distance of 0.91 m to 5.48 m from the athlete. The body regions of interest were the pectoralis major, sternal and clavicular portions, anterior deltoid and long head of the triceps brachii[5,15]. The region of interest evaluated was the anterior and posterior faces of the trunk and arms[23] (Fig. 2).

Statistical analysis

The descriptive statistics were performed using measures of central tendency, mean (X) ± Standard Deviation (SD) and 95% confidence interval (95% CI). To check the normality of the variables, the Shapiro–Wilk test was used, considering the sample size. Data for all analyzed variables were homogeneous and normally distributed. To evaluate performance, two-way ANOVA within repeated measures was used[24] was performed, with Bonferroni Post Hoc, in two conditions (TT and ET), and at four moments (before, after, 24 h and 48 h), considering the values: low effect (≤ 0.05), medium effect (0.05 to 0.25), high effect (0.25 to 0.50) and very high effect (> 0.50). For the t test, an effect size (Cohen's d) was considered, adopting the values: low effect (≤ 0.20), medium effect (0.20 to 0.80), high effect (0.80 to 1, 20) and very high effect (> 1.20))[25]. The statistical treatment was performed in SPSS, version 22.0 (IBM, Armonk, NY, USA). The significance level adopted was $p < 0.05$.

The sampling power was calculated a priori using the open software G*Power version 3.1.9.6 (University of Kiel, Germany), with the "F family (ANOVA)" considering a standard f = 0.8, α < 0.05, 1 − β = 0.80. Hence, it was possible to estimate a sampling power of 0.88 for a minimum sample of twelve subjects per group, suggesting that the study has statistical strength to answer the research[5]. This can be confirmed from the partial mean values of Eta squared (η2p = 0.425) found and classified as a high effect[24].

Results

The sample consisted of 12 male athletes with national and international participation representing the Brazilian Paralympic Committee and the World Para Powerlifting (WPPO)[1], aged 30.25 ± 8.13 years, meeting our inclusion criteria and successfully completing all specified tests. The sample characteristics are detailed in Table 2, using descriptive statistics with mean and standard deviation for each variable.

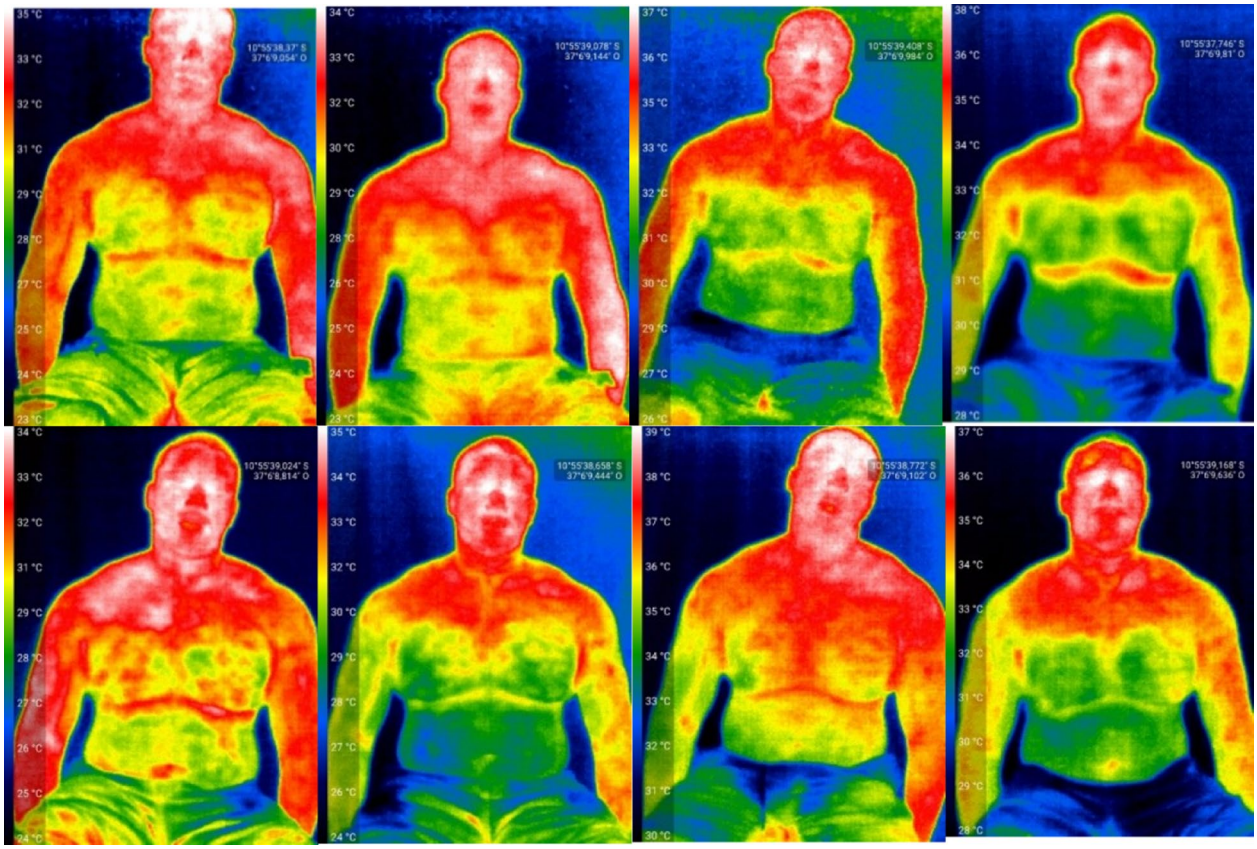

Fig. 1. Illustration of thermal images at before, after, 24 h and 48 h in TT and ET, respectively.

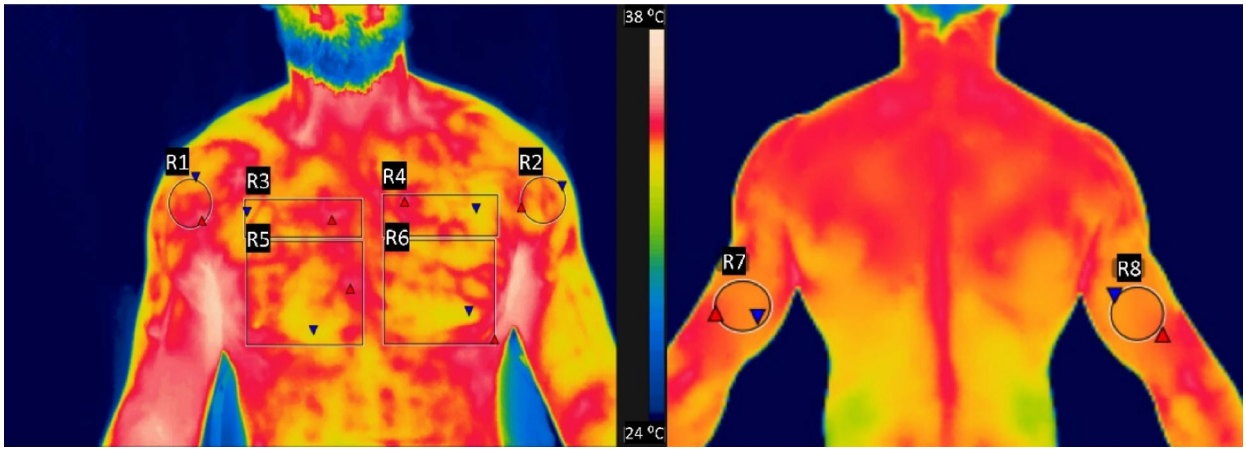

Fig. 2. Illustration of the regions of interest (ROI) in the thermal images acquired.

Figure 3 presents the results of muscle activation through surface electromyography (sEMG) (A) Peak and (B) Average, of different muscle groups.

There was no difference between muscle electrical activity (EMG) in different muscles in relation to Traditional and Eccentric Training ($p > 0.05$).

Figure 4 shows the results of skin temperature (Thermo) in the muscles (A) Pectoralis Major Sternal portion, (B) Pectoralis Major Clavicular portion, (C) Anterior Deltoid, and (D) Brachii Triceps, in the moments before, after, 24 h and 48 h.

(A) There was a difference in Eccentric Training, at the Before moment related to the 24-h period ("a" $p = 0.022$; an increase of 2.17 °C; 6.28%) and related to the 48-h period ("b" $p = 0.030$; the increase of 2.08 °C; 6.05%; η2p = 0.177, Medium Effect). (B) There was a difference in Eccentric Training between the Before and 24-h moments ("a" $p = 0.011$; the increase of 2 °C; 5.71%) and 48 Hours ("b" $p = 0.049$; the increase of 1.92 °C;

Variables	Value
Age (years)	30.25 ± 8.13
Experience (years)	5.92 ± 1.37
Body weight (Kg)	72.36 ± 18.47
1RM test in bench press (Kg)	125.00 ± 37.83
1RM/Body weight	1.74 ± 0.31

Table 2. Characterization of the sample. RM, repetition maximum in bench press. Values expressed as mean and standard deviation.

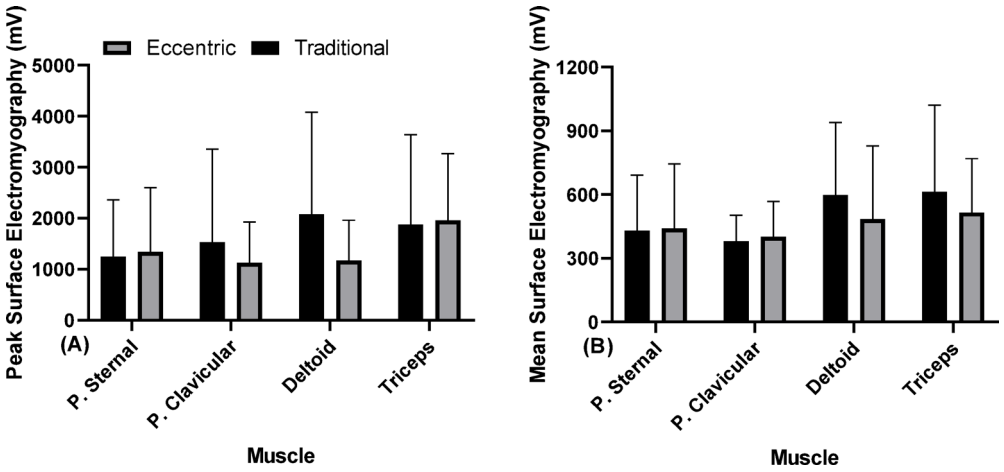

Fig. 3. The muscle electrical activity through surface electromyography (sEMG) (**A**) Peak and (**B**) Average, of the different muscle groups. Legend: Pectoralis Major Sternal Portion (P. Sternal), Pectoralis Major Clavicular Portion (P. Clavicular), Anterior Deltoid (Deltoid), Triceps Brachii, Long Head (Triceps). Values represented by mean and standard deviation.

5.49%; η2p = 0.192, Medium Effect). There was also a difference in the 24-Hour Moment between Eccentric and Traditional Training ("*" $p = 0.020$; the increase of 1.58 °C; 4.52%; η2p = 0.213, Medium Effect). (C) There was a difference in Eccentric Training between the Before and 24-Hour moments ("a" $p = 0.012$; the increase of 1.83 °C; 5.21%; η2p = 0.202, Medium Effect). There was also a difference in the 24-Hour Moment between Eccentric and Traditional Training ("*" $p = 0.016$; the increase of 1.58 °C; 4.50%; η2p = 0.228, Medium Effect). (D) There was a difference in Eccentric Training between the Before and After moments ("a" $p = 0.014$; the increase of 1.08 °C; 3.27%;) and 48 h ("b" $p = 0.028$; the increase of 1 0.33 °C; 3.99%; η2p = 0.421, High Effect). Also, there was a difference in the 24-Hour Moment between Eccentric and Traditional Training ("c" $p = 0.028$; the increase of 1.08 °C; 3.24%; η2p = 0.143, Medium Effect).

The Fig. 5 shows the results of (A) Maximum Isometric Force (MIF) and (B) Time until Maximum Isometric Force (Time), in the moments before, after, 24 h and 48 h later.

(A) There was a difference in Traditional training, between the moments before and after ("a" $p = 0.003$; reduction of 120.37N; − 19.36%;), between the moments after and 48 h ("b" $p = 0.002$; increase of 159.20N; 20.38%;) and between 24 and 48 h ("c" $p = 0.005$; increase of 129.34N; 16.56%;). In Eccentric training, there were differences between the moments before and after ("d" $p = 0.001$; reduction of 137.19N; − 23.45%;) and between after and 48 h ("e" $p = 0.034$; increase of 85 0.52N; 12.75%; η2p = 0.494, High Effect). There were also differences at the 48-h time point between Traditional and Eccentric training ("*" $p = 0.004$; The TT was greater than the ET at 110.50N; 14.15%; η2p = 0.360, High Effect). (B) There was no difference in relation to Time until MIF ($p > 0.05$).

Discussion

The objective of this study was to evaluate the acute effects of different strength training methods (traditional and eccentric) on static strength indicators (maximum isometric force and time until maximum isometric force), muscle activation and skin temperature in athletic athletes Paralympic Powerlifting, after 3 weeks of traditional training (80% of 1RM) and eccentric training (110% of 1RM).

Corroborating our hypothesis I, an increase in Thermo was observed 24 h after Eccentric training (3.27–6.28%), in addition to an increase in Thermo among the training methods evaluated (3.24–4.52%) during the bench press. These elevations in Tsk in athletes identify a systemic inflammatory response following training methods. In relation to our hypothesis II, a reduction in strength was found in the initial phase (− 19.36%), followed by an increase in the final phase (20.38%) of traditional training. Likewise, in relation to eccentric

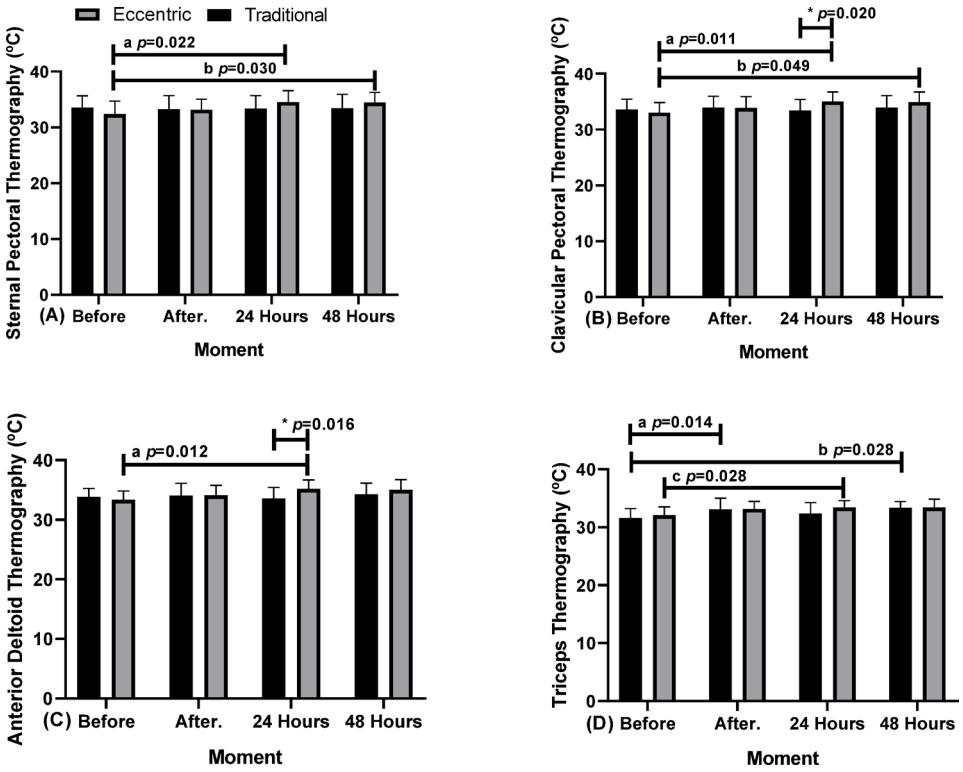

Fig. 4. Skin temperature in the muscles (**A**) pectoralis major sternal portion, (**B**) pectoralis major clavicular portion, (**C**) anterior deltoid, and (**D**) Brachii Triceps, in the moments before, after, 24 h, and 48 h. Values represented by mean and standard deviation.

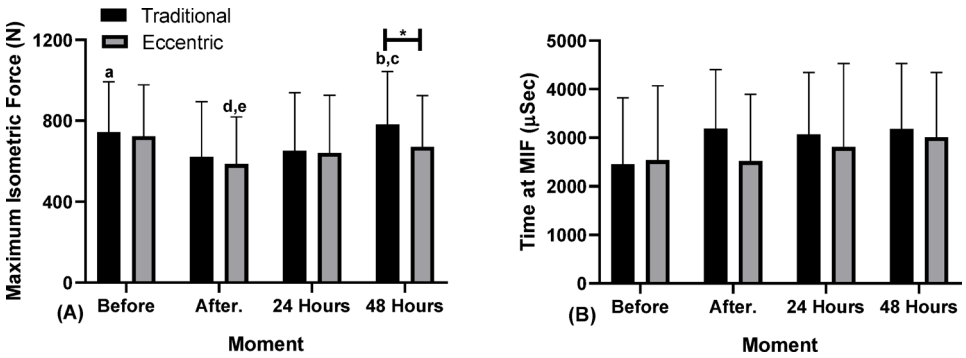

Fig. 5. (**A**) Maximal isometric force (MIF) and (**B**) Time until maximum isometric force (Time), in the moments before, after, 24 h and 48 h later. Values represented by mean and standard deviation.

training, there was a reduction in the initial phase (−23.45%), followed by an increase in the final phase (12.75%). However, no significant difference was observed in relation to Time. In relation to our hypothesis III, although the Deltoid was requested more during the movement, no statistical difference was observed in muscle activation between the training methods evaluated.

Thermography

The infrared thermography allows qualitative and quantitative analyzes to be carried out, identifying regions of hyperthermia/hypothermia, which contributes to the assessment of the athlete's physical state. This physiological process is associated with heat transfer by methods such as convection, conduction, radiation and evaporation[26]. This condition differs from biochemical markers, such as creatine kinase, which do not determine the anatomical location of the site that presents the greatest inflammatory process[22]. It is known that the more vascularized the injured area, the faster the healing will be, compared to poorly vascularized areas.

In the Eccentric training method, an increase in Thermo was observed after 24 h in all muscles evaluated, remaining increased until 48 h after training in the pectoralis major muscle, sternal portion, which indicates

changes in blood flow in the areas of interest. Thus, changes in skin temperature occurred after exercise in the muscles studied, indicating a systemic inflammatory response[27]. These changes occurred mainly 24 h after exercise, as demonstrated by Dindorf[28] who observed that in this 24-h period the subjects' temperature returned to its initial state, reporting uncertainties in the temperature for the 48-h period. Our study investigated these changes within 48 h, as according to Stewart[27] this is the moment when the increase in Thermo arrives. The increase in temperature in the 24 h and 48 h post-exercise may reflect a delay in the anti-inflammatory response[15]. These differences in thermoregulatory processes may occur because trained individuals delay the increase in Thermo[28]. Hence, the muscle recovery process tends to increase Thermo up to 96 h after exercise, especially after high-intensity exercise[29].

The eccentric training promoted an increase in Thermo in up to 24 h in the muscles involved, compared to Traditional training. While increases in blood flow and skin temperature are indicators of muscle fatigue, measurable Thermo is linked to thermoregulatory effects such as skin blood flow or sweat gland activity[28]. This would be justified by the greater stimulation of vasoconstrictor responses, controlled by the adrenergic nerves of the sympathetic nervous system and modulated by the action of noradrenergic neurotransmitters[22]. Intense exercise tends to induce an initial decrease in body temperature, followed by a subsequent increase due to the resulting inflammatory process. This thermal variation was discussed by Neves[29], who suggests that, while the temperature rise is generally attributed to local inflammation, it may also be associated with the application of a localized vascular stimulus. This stimulus, in turn, could trigger a systemic endothelial adaptation. However, the direct relationship between this adaptation and the delayed temperature increase still requires further investigation to be fully understood.

Another explanation that can be found about the effect of ET in relation to TT is the load used, reaching a 30% difference in 1RM in the overload used in the methods, which could play an important role in directing blood flow. In this sense, elevations of pro-inflammatory cytokines are observed immediately after eccentric muscle injury, while circulating levels of C-reactive protein have been demonstrated uniformly at the time point 24 h after exercise[28]. Furthermore, measuring Tsk in individuals who use a wheelchair to move around during the assessment is difficult, making a true resting point difficult[4].

Surface electromyography

Our study found no significant differences in EMG activity between the performed training methods. Although greater muscle activity was observed in the anterior deltoid (AD) muscle, the difference was not statistically significant ($p > 0.05$).

The sEMG allows estimating which muscles are predominantly involved in the kinetics of a specific movement[20]. A similar non-significant finding was reported by Gottschall[30], who compared sEMG in various muscles during bench press and push-up exercises in beginner and advanced subjects. In their study, the authors reported that the anterior deltoid exhibited lower sEMG during the bench press, aligning with our non-significant result. Likewise, Alizadeh[31], in an investigation of sex-related sEMG during push-up and bench press exercises, found lower sEMG during the eccentric phase of the bench press movement, without statistical significance. In a separate study, Mendonça[16] compared sEMG in Paralympic Powerlifting athletes, observing a significant difference in the anterior deltoid muscle, however, this analysis involved partial repetitions. The direct relationship with muscle engagement during the bench press exercise is attributed to the high motor unit recruitment observed during the training session. This response occurs due to the demand for maximal force generation in lifts performed with loads exceeding 80% of 1RM.

Maximal isometric force and time

As for MIF in Traditional training, there was a reduction in strength in the initial phase, followed by an increase in the final phase. This finding is widely described in the literature as a response after a training session. In relation to Eccentric training, there was a reduction in the initial phase, continuing up to 48 h after the procedure. Qualitative and quantitative changes in tendon tissue that may be related to the magnitude of imposed stretch have also been reported with Eccentric training. The inclusion of eccentric loads appears to be superior to traditional training in the improvement associated with strength, power and speed performance[13].

The eccentric training showed an increase in MIF 48 h after the procedure. Other studies observed that MIF would be associated with range of movement[16] and pointed out that wider movements would induce greater fatigue, with greater loss in maximum isometric strength. It was also observed that the use of variable resistance (elastic bands) tends to promote greater loss of strength and increase fatigue in Paralympic Powerlifting athletes[8]. These findings corroborate ours, where athletes showed an increase in strength indicators in the TT method in relation to the ET method, indicating that the subjects continue to feel fatigue even after training.

The strength is supported by a combination of morphological and neural factors, including area motor unit recruitment, speed coding, motor unit synchronization, and neuromuscular inhibition. Traditional and Eccentric training can produce strength and power benefits, which may vary according to training time, type of muscle fiber and athlete's genetics. In our study, no significant difference was observed in relation to Time until Maximum Isometric Force ($p > 0.05$). A decrease in strength following a maximal training session is expected due to the mechanical stress induced by muscle contractions. In our study, although no statistically significant differences were observed, the ET exhibited greater fatigue and stress. This response may be associated with a decline in strength, characterized by a greater amplitude of reduction in Maximum Isometric Force.

Limitations

Our study has some limitations, as our athletes participate in a sport that has a single classification, not divided by disability, which could have different results. Differences in body weight were not taken into account, as lighter athletes tend to have greater relative strength and heavier athletes tend to have greater absolute strength, which

could interfere with the results if they were separated by body weight category. Future research should investigate how best to implement traditional and eccentric training and examine how strength affects an athlete's ability to improve performance after various training methods.

Conclusions

In the present study, it was determined that the muscles involved in the bench press exercise showed a notable increase in skin temperature (Thermo) after implementing the Eccentric training method (ET) in contrast to the traditional method (TT). This observation was noted in the acute response to the bench press exercise, indicating a high occurrence of muscle fatigue. Additionally, there was a substantial increase in the production of Maximum Isometric Force (MIF) after performing Eccentric training, emphasizing its influence not only on muscular fatigue, but also on a further increase in the production of muscular force.

In practical application, as mentioned previously, the Eccentric training method (ET) appears to be more effective in the acute response to the bench press exercise, attributed to the use of heavy weights and resulting in greater neuromuscular adaptations. However, it is essential to recognize that muscle recovery time tends to be prolonged. Coaches must meticulously evaluate, plan and periodize the chosen training method and recovery period for Paralympic Powerlifting athletes.

Data availability

Data sets generated during the current study are available from the corresponding author on reasonable request.

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Author contributions

Conceptualization, J.A.S.L.J. and F.J.A.; methodology, F.J.A; software, J.L.M.; validation, P.F.A.N., B.G.A.T.C. and A.F.S.; formal analysis, G.B.; investigation, C.J.B.; resources, R.F.S.; data curation, J.A.S.L.J.; writing—original draft preparation, H.N.; writing—review and editing, G.B., F.H.Y., F.M.C, A.F.A; visualization, A.F.S; supervision, A.F.A and F.J.A

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board and approved by the Human Research Ethics Committee of the Federal University of Sergipe (UFS), under Statement Number 2637882/2018.Written informed consent was obtained from all individual participants included in the study.

Additional information

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ARTIGO 2

EFEITOS AGUDOS DO TREINO EXCÊNTRICO VERSUS TRADICIONAL SOBRE FORÇA ISOMÉTRICA, POTÊNCIA E TERMORREGULAÇÃO EM ATLETAS DE *POWERLIFTING* PARALÍMPICO.

Acute Effects of Eccentric versus Traditional Training on Isometric Strength, Power and Thermoregulation in Paralympic Powerlifting Athletes

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Abstract

Paralympic Powerlifting (PP) is a strength-based sport in which the objective is to lift the highest possible load in the bench press exercise while maintaining proper technique. The traditional training method (TT) is considered the safest, while the eccentric training method (ET) is characterized by lower energy cost and greater load capacity. This study investigated the acute effects of different strength training methods (TT and ET) on 19 elite male PP athletes ranked among the top 10 in their respective weight categories. The following variables were assessed before, immediately after, and 24 and 48 hours post-training: maximal isometric force (MIF), skin temperature (Tsk), maximal velocity (Vmax), variability, and power. In the TT protocol, loads equivalent to 80% of 1RM were used during both concentric and eccentric phases; in the ET protocol, loads were set at 80% of 1RM for the concentric phase and 110% of 1RM for the eccentric phase. Results indicated that ET induced an increase in Tsk in the pectoralis major and anterior deltoid muscles 48 hours after exercise, suggesting greater muscle damage and inflammatory response. MIF recovery was slower following ET, whereas TT showed full recovery and even higher values after 48 hours. Variability was greater in the ET condition, indicating less performance consistency. Both Vmax and power showed immediate decreases in both methods, with more efficient recovery observed in TT. In conclusion, ET elicits intense neuromuscular responses with potential for long-term adaptive gains, but requires extended recovery time. Conversely, TT appears more appropriate for maintenance phases, due to reduced muscle disruption and faster restoration of function.

Keywords: eccentric training, isometric strength, neuromuscular adaptations, powerlifting, elite athletes.

1. Introduction

Strength training is widely recognized for its effectiveness in enhancing muscular strength, power, and hypertrophy, and is employed in both athletic and clinical populations (Refsnes et al., 2025). Powerlifting is a sport focused on maximal strength development and consists of three movements: squat, bench press, and deadlift (*Federação Internacional de Powerlifting IPF - Federação Internacional de Powerlifting IPF*, s. d.). Paralympic Powerlifting (PP) is a strength-based sport involving athletes with lower limb impairments, in which the competitive goal is to lift the highest possible load in the bench press, following standardized technical criteria (*IPC - Paralympics News, Sports and Results*, s. d.). Although both sports share the same goal—lifting the heaviest possible weight in their respective events—they differ in technique and training methodology (Tung et al., 2024). While the movement is focused on the upper body, elite Paralympic athletes exhibit exceptional strength levels, often surpassing world records set by able-bodied athletes, as evidenced by recent comparative analyses (van den Hoek et al., 2023). These findings not only challenge conventional paradigms regarding performance in athletes with disabilities but also highlight the effectiveness of neuromuscular, biomechanical, and psychological adaptations resulting from intensive training.

Beyond its competitive value, PP has been proposed as a sustainable and safe strategy for improving muscle strength in individuals with spinal cord injuries and other physical disabilities, contributing to functional rehabilitation, self-esteem, and quality of life (Aidar et al., 2022; Teles et al., 2021). Studies involving elite Paralympic athletes also emphasize the influence of variables such as elastic resistance, variable overload, and velocity control on performance outcomes such as power, skin temperature, and neuromuscular fatigue (Filho et al., 2024; Santos et al., 2023). These findings underscore the importance of scientifically investigating different training strategies, with a focus on acute responses and practical applicability. (Refsnes et al., 2025)) demonstrated that performing eccentric training (ET) sessions one to three times per week can lead to significant strength and muscle growth adaptations, highlighting the importance of balancing stimulus and recovery.

Among the most commonly used methods in strength athlete preparation are traditional training (TT), which balances concentric and eccentric actions,

and eccentric training (ET), which emphasizes the eccentric phase using loads exceeding 100% of 1RM (de Souza Leite Júnior et al., 2025; Taber et al., 2021). While TT is associated with safe and progressive strength development, ET has a greater potential to induce muscle damage, oxidative stress, and neural adaptation—particularly due to the recruitment of type II muscle fibers and increased motor control demands (Franchi et al., 2017; Hody et al., 2019). However, the acute effects of these methods on variables such as isometric strength, velocity, power, force variability, and pain perception remain poorly understood in athletes with disabilities, limiting individualized load prescription in high-performance contexts (Soares Freitas Sampaio et al., 2020).

Given this context, the present study aimed to analyze the acute effects of different strength training methods (TT and ET) on maximal isometric strength, pain sensitivity (via pressure algometry), maximum velocity, variability, and power in elite Paralympic Powerlifting athletes. Considering the greater physiological stress imposed by ET, we hypothesize that this method will elicit more intense neuromuscular and perceptual responses compared to TT, which may have direct implications for training session and cycle planning.

2. Methods

This study employed a crossover design involving Paralympic Powerlifting (PP) athletes from the Federal University of Sergipe, Brazil. Each participant served as their own control, with assessments conducted over a three-week period: familiarization (week 1), traditional training (TT, week 2), and eccentric training (ET, week 3). All sessions took place between 9:00 a.m. and 12:00 p.m. in a climate-controlled environment (~25°C), according to athlete availability.

The following variables were measured during the application of the TT and ET protocols, each performed in a single training session: maximal isometric force (MIF), skin temperature (Tsk), maximal velocity (Vmax), variability (Variab), and power output (Pot). All participants were previously accustomed to high-intensity strength training with loads exceeding 80% of 1RM and routinely applied various training methods throughout their annual periodization.

In the TT protocol, a constant load of 80% of 1RM was used during both the concentric and eccentric phases of the bench press movement (Austin & Mann, 2012). For the ET protocol, the concentric phase was performed with a load of 80% of 1RM, while the eccentric phase involved a supramaximal load of 110% of 1RM (Taber et al., 2021). At the end of the eccentric phase, 30% of the additional load was removed from the bar, leaving 80% of the total load for the concentric phase. During all sessions, verbal encouragement was provided to ensure maximal effort. Measurements of MIF, Variab, Tsk, Vmax, and Pot were collected at four time points: baseline (pre), immediately post-exercise (post), 24 hours post, and 48 hours post-exercise, as detailed in Table 1.

Table 1. Experimental drawing – Weekly test schedule.

Weeks	Day 1	Day 2	Day 3	Other days
Week 1 (Familiarization) ➔ 1RM, MIF, Variab, Tsk, Vmax e Pot	Before, after	24h	48h	Rest
Week 2 (Traditional Training) ➔ 1RM, MIF, Variab, Tsk, Vmax e Pot	Before, after	24h	48h	Rest
Week 3 (Eccentric Training) ➔ 1RM, MIF, Variab, Tsk, Vmax e Pot	Before, after	24h	48h	Rest

Legend: 1RM: One Repetition Maximum; MIF: Maximal Isometric Force; Variab: Variability; Tsk: Skin Temperature; Vmax: Maximum Velocity; Pot: Power. The tests were performed using the bench press exercise approved by the WPPO (*WPPO*, s. d.).

2.1. Sample

Nineteen elite male athletes participated, each ranked among the top 10 in their respective categories. Inclusion criteria included at least 18 months of competitive experience and eligibility confirmed by the Brazilian Paralympic Committee. All participants voluntarily took part in the study and signed an informed consent form, in accordance with Resolution 466/2012 of the National Commission for Research Ethics (CONEP) of the Brazilian National Health Council (CNS), and in compliance with the Declaration of Helsinki (1964, revised in 2013) of the World Medical Association. This study was approved by the Research Ethics Committee of the Federal University of Sergipe (ID-CAAE:

67953622.7.0000.5546) under approval number 6.523.247, dated November 22, 2023.

Table 2. Sample characteristics.

Variable	Values
Age (years)	31.00 ± 6.32
Experience (years)	6.09 ± 1.30
Body mass (kg)	73.75 ± 17.63
Bench press 1RM (kg)	140.91 ± 42.53*
1RM / Body mass	1.77 ± 0.39**

Legend: Athletes were ranked among the top 10 in their respective national weight categories based on lifted loads. A 1RM-to-body mass ratio above 1.4 is considered indicative of elite status among competitors (Ball & Weidman, 2018; van den Hoek et al., 2023).

2.2. Instruments

Body mass was measured with the athletes seated on a wheelchair-adapted electronic scale (Mic Wheelchair model, Micheletti, São Paulo, Brazil), with a maximum capacity of 300 kg. The bench press exercise was performed using official Paralympic Powerlifting equipment, including bench, barbell, and collars(*WPPO*, s. d.), according to international competition standards.

Dynamic strength parameters, including maximum velocity and power, were measured using a Speed4Lift SL® linear position transducer (Móstoles, Madrid, Spain) (Pérez-Castilla et al., 2019). Data were collected before and after a training session with a submaximal load equivalent to 45% of 1RM, in which the estimated mean velocity was approximately $1.0 m \cdot s^{-1}$ (Sanchez-Medina et al., 2010; Sánchez-Medina & González-Badillo, 2011). These dynamic parameters were also compared between the first and last sets of a five-set protocol (5 × 5RM) using 80% of 1RM.

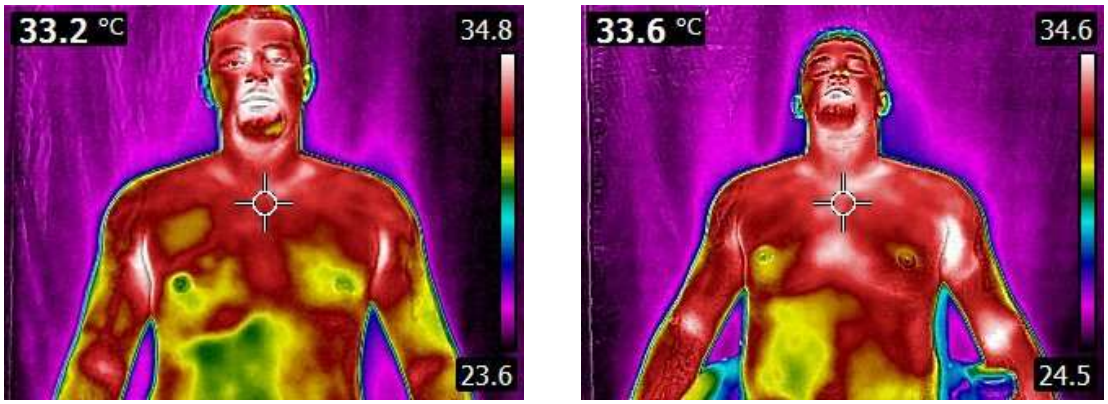
Static strength parameters, including maximal isometric force (MIF) and variability, were measured using a Chronojump load cell (Chronojump BoscoSystem, Barcelona, Spain) (Mendonça et al., 2021), 2021), with a capacity of 500kg, output impedance of 350 ± 3 ohms, insulation resistance above 2.000cc, input impedance of 365 ± 5ohms, and a 24-bit analog-to-digital converter operating at 80 Hz. The perpendicular distance between the load cell and the center of the bench was used as the reference point (Teles et al., 2021).

MIF was defined as the maximum force generated by the upper limb muscles during the bench press exercise. Maximal isometric force, measured in

Newtons (N), was calculated using the formula N = M × g, where M represents mass in kilograms and g is the acceleration due to gravity (9.80665m/s²). The measurement was taken between the cable attachment point of the load cell and the bench press apparatus. During the isometric test, athletes' elbows were positioned at approximately 90°, confirmed using a pendular goniometer (Model FL6010, Sanny, São Paulo, Brazil). Athletes were instructed to perform a maximal voluntary contraction by attempting to extend their elbows as quickly and forcefully as possible to assess MIF. To measure the time to MIF, participants maintained maximal contraction for 5 seconds (Soares Freitas Sampaio et al., 2020; Teles et al., 2021).

For thermographic image acquisition, a room was prepared with artificial lighting and environmental control, including temperature regulation via air conditioning and monitoring with a thermo-hygrometer (Hikari HTH-240, Hikari, Shenzhen, China) (Santos et al., 2023). The temperature was maintained between 22–24°C, and relative humidity was kept at approximately 50% (Aidar et al., 2022). Using a thermal imaging camera, it is possible to detect infrared radiation within the electromagnetic spectrum and convert this energy into data on skin surface temperature, which is directly related to local blood flow.

Proper preparation was conducted prior to thermogram acquisition. Athletes were instructed to refrain from any physical exercise during the 24 hours preceding the test and to avoid the consumption of caffeine, stimulants, and alcohol (Fernández-Cuevas et al., 2015) Thermal images were captured using a FLIR T640sc infrared camera (FLIR Systems, Stockholm, Sweden), featuring a temperature detection range of –40°C to 2.000°C, accuracy of 2%, thermal sensitivity < 0.035°C, infrared spectral band of 7.5 to 14 μm, frame rate of 30Hz, and resolution of 640 × 480 pixels. The camera was positioned at a distance ranging from 0.91m to 5.48m from the athlete. Thermal image analysis was performed using FLIR TOOLS software (FLIR Systems, Stockholm, Sweden). Regions of interest (ROIs) included the pectoralis major (sternal and clavicular portions), anterior deltoid, and the long head of the triceps brachii (de Souza Leite Júnior et al., 2025).



A) B)

Figure 1. Illustration of thermographic images during different training methods. (A) Traditional training, (B) Eccentric training.

2.3. Procedures

During the familiarization week, body mass and bench press 1RM were assessed (*IPC - Paralympics News, Sports and Results*, s. d.). The traditional training (TT) protocol used 80% of 1RM in both concentric and eccentric phases, while the eccentric training (ET) protocol applied 80% of 1RM in the concentric phase and 110% in the eccentric phase, with removal of 30% of the extra load at the end of the eccentric phase. Maximal isometric force (MIF), skin temperature (Tsk), maximal velocity (Vmax), variability (Variab), and power output (Pot) were measured before, immediately after, 24 hours, and 48 hours post-training. Each athlete performed a single repetition with the tested load, adjusted in increments or reductions of 2.4 to 2.5% until reaching the 1RM value. Recovery intervals between attempts ranged from 3 to 5 minutes (Resende et al., 2020). At the beginning of each test session, athletes completed a warm-up targeting the muscles involved in the movement, consisting of three sets of 10 to 20 repetitions. Subsequently, a specific warm-up for the bench press was performed, using 30% of the 1RM load with 10 slow repetitions followed by 10 fast repetitions(Teles et al., 2021).

2.3. Statistical Analysis

Data were analyzed using SPSS 22.0 software, with significance set at $p < 0.05$. Sample power was calculated with G*Power (effect size $f = 0.8$; $\alpha < 0.05$; $1-\beta = 0.80$), indicating robustness with a sample size of $n = 12$. Two-way ANOVA with Bonferroni post hoc and *t*-tests for effect size (Cohen, 1992) were applied.

Descriptive statistical analysis was performed using measures of central tendency, presenting the mean (X) ± standard deviation (SD) and 95% confidence intervals (95% CI). The Shapiro-Wilk test was applied to assess the normality of the variables, taking sample size into account. All analyzed variables demonstrated homogeneity and normal distribution. Performance was evaluated using two-way ANOVA (Cohen, 1992), followed by Bonferroni post hoc tests, considering two conditions (TT and ET) and four time points (pre, post, 24 h, and 48 h). Effect sizes were classified as small (≤ 0.05), medium (0.05 to 0.25), large (0.25 to 0.50), and very large (> 0.50). The t-test was also employed for effect size analysis (Cohen's d), adopting the following classifications: small (≤ 0.20), medium (0.20 to 0.80), large (0.80 to 1.20), and very large (> 1.20) (Cohen, 1992; Lakens, 2013).

3. Results

The results presented in Figure 1 indicate that there was a significant difference in skin temperature (Tsk) following eccentric training (ET) in the Pectoralis Major muscle at 48 hours post-training (34.29 ± 1.76°C, 95% CI: 33.45–35.14, "b" p = 0.022; F = 5.817; η^2p = 0.244; medium effect), in the Anterior Deltoid muscle at 48 hours post-training (34.34 ± 1.41°C, 95% CI: 33.66–35.20, "b" p = 0.012; F = 10.124; η^2p = 0.244; medium effect), and in the Long Head of the Triceps Brachii at 48 hours post-training (32.53 ± 1.48°C, 95% CI: 31.82–33.25, "b" p = 0.018; F = 2.053; η^2p = 0.102; very high effect).

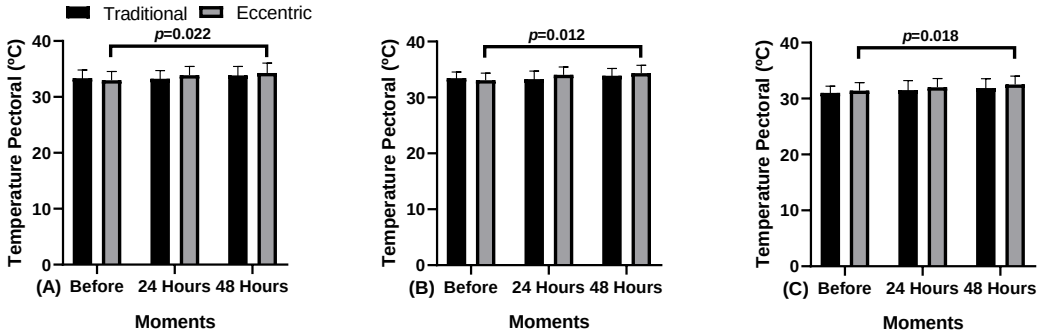


Figure 1. Skin temperature (Tsk) (Mean ± SD; 95% CI) at different time points following Traditional Training and Eccentric Training in Paralympic powerlifting athletes.

The results presented in Table 3 indicate that, regarding maximal isometric force (MIF), there was a significant difference in the TT group at 48 hours post-exercise (811.75 ± 196.76 m/s, 95% CI: 716.91–906.58; “c” p = 0.038; F = 5.094; η^2p = 0.221; very large effect), as well as in the ET group at the same time point (740.45 ± 219.66 m/s, 95% CI: 634.58–846.33; “d” p = 0.010; F = 5.094; η^2p = 0.221; very large effect). A significant difference was also observed between the TT and ET methods at 48 hours post-exercise (p = 0.037; F = 0.781; η^2p = 0.042; large effect), with higher MIF values in the TT condition. No significant differences were found in variability (p = 0.155).

Table 3: Maximal Isometric Force (MIF) and Variability (Variab) (Mean ± SD; 95% CI) at Different Time Points during Traditional Training and Eccentric Training in Paralympic Powerlifting.

	MIF (m/s)	Variab
Before Traditional	729.84±252.30	1.50±1.04
“a”	(608.23-851.44)	(1.00-2.00)
Before Eccentric	727.69±214.69	1.87±1.03
“b”	(624.21-831.17)	(1.37-2.37)
After Traditional	657.00±271.55	1.60±1.39
“c”	(526.11-787.89)	(0.93-2.27)
After Eccentric	666.06±197.85	2.03±0.80
“d”	(570.70-761.42)	(1.64-2.42)
24hs Traditional	724.58±241.50	1.73±0.82
“e”	(608.18-840.99)	(1.33-2.12)
24hs Eccentric	697.22±232.13	1.60±0.60
“f”	(585.34-809.10)	(1.31-1.89)
48hs Traditional	811.75±196.76 c	1.88±1.00
“g”	(716.91-906.58)	(1.40-2.36)
48hs Eccentric	740.45±219.66 d,g	2.03±0.85
“h”	(634.58-846.33)	(1.63-2.44)
p	c p=0.038 * d p=0.010 * g p=0.037 #	p=0.155
F	5.094 * 0.781 #	XXX
η2p	0.221 * 0.042 #	XXX

p≤0.05 (ANOVA two way and Post Hoc de Bonferroni). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 0.50, and very high effect (>0.50). * Intraclass, # Interclass.

The results presented in Table 4 indicate that for Vmax at 45% of 1RM, a significant difference was observed in the TT group at 24 hours post-training (1.14 ± 0.19 m/s, 95% CI: 1.05–1.23; “a” p = 0.005; F = 13.164; η^2p = 0.422; large effect). In the ET group, a significant difference was found immediately

post-training (1.07 ± 0.21 m/s, 95% CI: 0.97–1.17; “b” $p < 0.001$; F = 13.164; $\eta^2p = 0.422$; large effect). Additionally, for the ET group, significant differences were observed at the pre-training time point (1.24 ± 0.22 m/s, 95% CI: 1.14–1.35; “f” $p < 0.001$; F = 13.164; $\eta^2p = 0.422$; large effect) and again at pre-training (1.24 ± 0.22 m/s, 95% CI: 1.14–1.35; “h” $p < 0.007$; F = 13.164; $\eta^2p = 0.422$; large effect).

Regarding power output (Pot) at 45% of 1RM, a significant difference was observed in the TT group at 24 hours post-training (432.32 ± 146.93 W, 95% CI: 361.50–503.10; “a” $p = 0.008$; F = 13.364; $\eta^2p = 0.426$; large effect). In the ET group, significant differences were found immediately post-training (397.25 ± 148.96 W, 95% CI: 325.45–469.04; “b” $p = 0.002$; F = 13.364; $\eta^2p = 0.426$; large effect) and at the pre-training time point (460.05 ± 157.99 W, 95% CI: 383.90–536.20; “f” p = 0.001 and “h” $p = 0.005$; F = 13.364; $\eta^2p = 0.426$; large effect). A significant difference was also found between the TT and ET groups at 24 hours post-training (407.39 ± 135.21 W, 95% CI: 342.22–472.55; “h” $p = 0.030$; F = 10.684; $\eta^2p = 0.372$; large effect).

Regarding Vmax at 80% of 1RM, a significant difference was observed in the ET group at 24 hours post-training (0.52 ± 0.08 m/s, 95% CI: 361.50–503.10; “a” $p = 0.048$; F = 4.490; $\eta^2p = 0.200$; medium effect).

No significant difference was found in power output (Pot) at 80% of 1RM ($p = 0.162$).

Table 4 Maximum Velocity (Vmax) and Power at 45% of 1RM and First and Fifth Sets at 80% of 1RM (Mean ± SD; 95% CI) at Different Time Points Following Traditional and Eccentric Training in Paralympic Powerlifting.

	45%de 1RM		80%de 1RM	
	Vmax (m/s)	Pot (W)	Vmax (m/s)	Pot (W)
Before Traditional “a”	1.26±0.23 (1.15-1.37)	467.58±160.44 (390.25-544.91)	0.58±0.18 (0.50-0.67)	369.55±152.68 (295.96-443.14)
Before Eccentric “b”	1.24±0.22 f,h (1.14-1.35)	460.05±157.99 f,h (383.90-536.20)	0.57±0.09 (0.53-0.61)	367.38±120.10 (309.50-425.27)
After Traditional “c”	1.16±0.23 (1.05-1.27)	441.11±142.14 (372,60-509.61)	0.55±0.17 (0.47-0.63)	349.95±147.02 (279.09-420.81)
After Eccentric “d”	1.07±0.21 b (0.97-1.17)	397.25±148.96 b (325.45-469.04)	0.55±0.09 (0.51-0.59)	327.05±93.51 (281.98-372.12)
24hs Traditional “e”	1.14±0.19 a (1.05-1.23)	432.32±146.93 a (361.50-503.13)	0.54±0.15 (0.47-0.61)	341.90±137.46 (275.65-408.15)
24hs Eccentric “f”	1.09±0.20 (0.99-1.19)	407.39±135.21 e (342.22-472.55)	0.52±0.08 b (0.48-0.55)	320.77±115.65 (265.03-376.51)
48hs Traditional “g”	1.17±0.17 (1.09-1.25)	435.81±136.59 (369.97-501.64)	0.55±0.20 (0.46-0.65)	334.15±147.43 (263.09-405.21)
48hs Eccentric “h”	1.11±0.20 (1.02-1.21)	412.86±144.09 (343.41-482.31)	0.53±0.09 (0.48-0.57)	334.48±114.07 (279.49-389.46)

p	a *p* =0.005* b,f *p* <0.001* h *p* =0.007*	a *p* =0.008* b *p* =0.002* e *p* =0.030# f *p* =0.001* h *p* =0.005*	b *p* =0.048 *	*p* =0.162
F	13.164 *	13.364 * 10.684 #	4.490 *	XXX
ɳ2p	0.422 *	0.426 * 0.372 #	0.200 *	XXX

p≤0.05 (ANOVA two way and Post Hoc de Bonferroni). ɳ2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 0.50, and very high effect (>0.50). * Intraclass, # Interclass.

4. Discussion

The aim of this study was to analyze the acute effects of different strength training methods on maximal isometric force, skin temperature, maximal velocity, variability, and power in Paralympic powerlifting athletes. Eccentric contractions generate greater forces compared to other contraction types at a given angular velocity; additionally, they require less motor unit activation and incur lower metabolic cost. It is well established that the neural strategies controlling eccentric contractions differ considerably from those of concentric or isometric contractions (Duchateau & Baudry, 2014). Eccentric contraction has garnered increasing interest across various fields due to its unique physiological and mechanical characteristics.

Skin Temperature

Eccentric training (ET) induced a greater increase in skin temperature (Tsk), consistent with increased muscle damage and inflammation (Filho et al., 2024; Getirana-Mota et al., 2024; Resende et al., 2020), while traditional training (TT) favored faster recovery of maximal isometric force (MIF), possibly due to lower eccentric overload. Maximal velocity (Vmax) and power (Pot) reflected greater neuromuscular impact in ET, corroborating findings by (Hody et al., 2019). These findings align with studies indicating that ET is more effective for long-term hypertrophy and strength gains but incurs immediate costs to functional capacity (Roig et al., 2009). In Paralympic athletes,

adaptations may be modulated by factors such as pre-existing lower limb atrophy, suggesting the need for individualized periodization adjustments.

The body's thermoregulation system involves many factors and processes to maintain homeostasis. During exercise, homeostasis in general, and skin temperature in particular, are strongly influenced by skeletal muscle metabolismo (Fernández-Cuevas et al., 2015; Sillero-Quintana et al., 2022).). After exercise, metabolic activity remains elevated as a compensatory response during the catabolic recovery phase. Therefore, athletes may require a longer rest period (Fernández-Cuevas et al., 2015; Resende et al., 2020).

The study by (Santos et al., 2023) found an increase in skin temperature in both dominant and non-dominant limbs between pre- and post-training bench press sessions in Paralympic powerlifting athletes, which represents a population specifically addressed in our study. (de Souza Leite Júnior et al., 2025) observed that, under the eccentric training (ET) method, skin temperature (Tsk) increased 24 hours post-exercise and remained elevated up to 48 hours in the sternal portion of the pectoralis major muscle, indicating changes in blood flow within the targeted regions.

Our study found a statistically significant increase in skin temperature in the pectoralis major and anterior deltoid muscles 48 hours after eccentric training (ET) (34.29 °C and 34.34 °C, respectively) compared to traditional training (TT). This finding is consistent with the study by (Filho et al., 2024; Getirana-Mota et al., 2024) which reported significant differences in skin temperature 48 hours after a strength training session in the sternal portion of the pectoralis major, anterior deltoid, and triceps brachii muscles. This can be explained by the fact that eccentric training induces greater muscle damage and inflammatory response, which increases blood flow to the affected area, raising skin temperature. Additionally, these responses may be related to muscle regeneration and prolonged structural adaptation, which may potentially favor long-term strength gains.

Maximal Isometric Force and Variability

The results indicate that both training methods, TT and ET, led to an acute reduction in maximal isometric force (MIF) immediately after exercise, reflecting the neuromuscular and metabolic stress imposed by the session

(Sanchez-Medina et al., 2010). However, MIF recovery after 48 hours was more pronounced in the TT group, with higher values (811.75 ± 196.76 m/s) compared to pre-training, in contrast to ET (740.45 ± 219.66 m/s), which, although showing recovery, did not reach TT levels. This difference may be attributed to the lower magnitude of muscle damage induced by TT, whose uniform load (80% of 1RM in both phases) results in less disruption of muscle fibers and, consequently, a faster restoration of contractile capacity (Hody et al., 2019). In contrast, ET, with an eccentric overload of 110% of 1RM, likely produced greater muscle microtrauma and inflammatory response, prolonging the recovery process, as suggested by Douglas (Douglas et al., 2017).

Variability in performance was also more pronounced in the ET condition, indicating greater difficulty in maintaining force consistency after training. This finding aligns with the greater neuromuscular complexity of ET, which requires activation strategies distinct from those used in concentric or isometric contractions (Duchateau & Baudry, 2014), potentially affecting coordination and motor unit recruitment in the short term. In contrast, TT showed lower variability, suggesting greater functional stability, which may be advantageous in competitive contexts that demand precision and repeatability.

Regarding maximal velocity (Vmax) at 80% of 1RM, lower variability was observed between groups compared to the 45% 1RM load. However, both groups experienced an immediate post-training decline, followed by partial recovery after 24 and 48 hours, without returning to baseline values. This pattern may be related to the higher neuromuscular demands imposed by heavy loads, which amplify the impact of muscle damage, especially in ET (Suchomel et al., 2021). The persistence of reduced Vmax values suggests that neuromuscular control and the ability to generate rapid force remain impaired for up to 48 hours, particularly in ET, due to greater mechanical stress on fast-twitch muscle fibers (Walker et al., 2016). These findings reinforce the need to adjust recovery intervals according to the training method, considering the distinct effects on muscle function in Paralympic powerlifting athletes.

Maximal Velocity and Power

With regard to Vmax at 45% of 1RM, values showed a significant decline after eccentric training (1.07 ± 0.21 m/s) compared to traditional training (1.16 ±

0.23 m/s). This reduction in maximal velocity following eccentric training can be attributed to the greater degree of muscle damage induced by this method, which causes significant microlesions, resulting in slower recovery of contractile function (Hody et al., 2019). After 48 hours, the TT group showed Vmax values close to baseline (1.17 ± 0.17 m/s), while the ET group remained below initial levels (1.11 ± 0.20 m/s), suggesting that TT causes less muscle disruption and supports faster recovery of velocity.

Regarding power at 45% of 1RM, this variable followed a pattern similar to that of Vmax, with a significant reduction immediately after eccentric training (397.25 ± 148.96 W) compared to traditional training (441.11 ± 142.14 W). Power recovery was also slower in the eccentric group, with values 24 hours post-training still below baseline levels (407.39 ± 135.21 W), whereas the traditional group had nearly fully regained its power-generating capacity (432.32 ± 146.93 W) in the same period.

Regarding power at 80% of 1RM, a significant reduction was observed immediately after eccentric training (327.05 ± 93.51 W) compared to traditional training (349.95 ± 147.02 W), reflecting the greater difficulty in sustaining performance under heavy loads due to the mechanical stress of eccentric training (Hody et al., 2019). After 48 hours, power values for both groups (TT: 334.15 ± 147.43 W; ET: 334.48 ± 114.07 W) indicated partial recovery, although slower in the ET group. (Filho et al., 2024) reported lower power output under traditional and variable resistance training conditions (use of chains), where total resistance at the bench press angle did not result in greater acceleration. Velocity tends to decrease under heavier loads due to slower shortening of skeletal muscle fibers and higher force production (Santos et al., 2023), an inverse relationship explained by the mechanisms of muscle contraction (Hody et al., 2019; Walker et al., 2016). The applicability of velocity-based training control under heavy loads has been debated, with evidence suggesting that variations in training methods promote specific functional adaptations (Mesquita Souza et al., 2023; Soares Freitas Sampaio et al., 2020).

Suggestions for Future Research

The findings of this study are relevant for understanding the acute effects of training methods in Paralympic powerlifting athletes; however, they present statistical limitations due to the relatively small sample size (n = 19), which reflects the limited availability of competitive athletes with the specific characteristics required. The absence of a control group restricts direct comparisons that could help isolate the effects of training methods from external variables. Additionally, the lack of control over participants' nutritional intake and hydration levels may have introduced bias, as these variables directly influence muscle recovery and neuromuscular performance. Such factors may have contributed to variability in the observed results. Future studies are encouraged to investigate the effects of eccentric training on other muscle groups, such as the lower limbs in able-bodied populations, as well as in athletes with different types of disabilities, in order to expand the generalizability of the findings and deepen the understanding of the physiological responses to these training protocols.

5. Conclusion

Eccentric training significantly increased skin temperature (Tsk) in the pectoralis major and anterior deltoid muscles 48 hours after exercise, indicating greater muscle damage and intense neuromuscular adaptations, but with slower recovery of maximal isometric force (MIF), maximal velocity (Vmax), and power (Pot) compared to traditional training. In contrast, traditional training favored faster recovery and greater consistency in performance.

Based on these findings, the strategic use of eccentric training is recommended during periodization phases aimed at developing maximal strength and hypertrophy, such as in the base or general preparation stages. This approach takes advantage of its capacity to induce profound neuromuscular adaptations, provided that extended recovery intervals are implemented to mitigate the effects of muscle damage. On the other hand, traditional training is more suitable for periods close to competitions or during maintenance phases, where rapid restoration of functional capacity and performance stability are priorities, thus optimizing the preparation of Paralympic powerlifting athletes for competitive events.

Author Contributions

F.J.A., W.Y.H.d.S., S.d.C.M., A.N.-S., C.J.B., and P.T.N., contributed to the study conception and design. Material preparation and data collection and analysis were performed by W.Y.H.d.S., S.d.C.M., É.L.M.V., and E.A.-M. The first draft of the manuscript was written by F.J.A., D.I.V.P., and P.T.N. All authors commented on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

This study was performed in line with Resolution 466/2012 of the National Research Ethics Commission (CONEP) of the National Health Council and following the ethical principles of the Declaration of Helsinki (1964, revised in 2013) of the World Medical Association. This study was approved by the Research Ethics Committee of the Federal University of Sergipe (ID-CAAE: 67953622.7.0000.5546) under statement number 6.523.247, dated 22 November 2023.

Informed Consent Statement

All athletes voluntarily participated in this study and provided written informed consent.

Data Availability Statement

The data that support this study can be obtained at https://www.ufs.br, accessed on 08 July 2025, or the data will be made available on request.

Conflicts of interst

The authors declare no conflicts of interest.

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Footnotes

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ARTIGO 3

EFEITO DO TREINAMENTO EXCÊNTRICO NA MODULAÇÃO DO ESTRESSE OXIDATIVO E NA MELHORIA DA PERFORMANCE EM ATLETAS DE POWERLIFTING PARALÍMPICO

sports

MDPI

Article

Effect of eccentric training on oxidative stress modulation and performance enhancement in Paralympic powerlifting athletes

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Abstract

Background: Paralympic Powerlifting (PP) is a strength-based sport in which athletes aim to lift maximal loads in the bench press. Traditional training (TT) is widely used to improve performance; however, eccentric training (ET) has been proposed as an alternative strategy due to its ability to generate higher mechanical loads with lower metabolic cost. Despite its potential benefits, the acute effects of ET on oxidative stress, neuromuscular performance, and pain perception in elite PP athletes remain poorly understood. Methods: This study investigated the acute effects of TT and ET in 15 elite male PP athletes. Thiobarbituric acid reactive substances (TBARS), sulfhydryl groups (SH), rate of force development (RFD), maximal strength up to 1 second (MS1s), pressure pain threshold (PPT), and localized muscle strength were measured before, immediately after, and 24 and 48 hours post-exercise. TT employed 80% of 1RM in both concentric and eccentric phases, while ET used 80% for concentric and 110% for eccentric phases. Results: ET significantly increased SH at all post-exercise time points ($p < 0.001$) and reduced TBARS at 24 hours ($p = 0.047$), indicating changes in redox-related biomarkers and reduced TBARS. RFD increased 48 hours after ET, while MS1s decreased immediately after exercise but returned to baseline levels within 48 hours in both protocols. PPT and localized muscle strength responses varied depending on the muscle group analyzed, with ET showing favorable responses in selected muscle groups. Conclusions: Eccentric training elicited distinct acute redox and performance-related responses in elite PP athletes, with favorable effects observed in selected performance and recovery outcomes. However, these findings should be interpreted cautiously given the indirect nature of the oxidative stress biomarkers and the acute study design.

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Keywords: Eccentric training. Oxidative stress. Neuromuscular adaptations. Powerlifting; elite athletes

1. Introduction

Resistance training (RT) is a key strategy for promoting health, improving physical conditioning, and optimizing athletic performance, being directly associated with increases in muscle strength and power across different populations, including athletes [1]. In addition to its functional benefits, RT induces favorable metabolic adaptations, such as enhanced insulin sensitivity and improved lipid profiles, thereby contributing to the prevention of chronic conditions such as sarcopenia and type 2 diabetes [2]. From a physiological perspective, maximal muscle strength gains associated with RT result from a complex process of neuromuscular adaptation, which involves both morphological changes in muscle fibers and modifications in the neural control of movement [3]. Eccentric exercises performed at elongated muscle lengths promote greater corticospinal and spinal plasticity, thereby optimizing neuromuscular adaptations and strength development [4].

In this context, RT has been established as an effective strategy not only for healthy populations but also for individuals with specific needs, such as Paralympic athletes [3,5]. Among the different methods employed, eccentric training (ET) stands out [4] demonstrated that ET performed at elongated muscle lengths promotes an increase in corticospinal excitability, as evidenced by the elevation of motor evoked potential amplitude and the reduction of motor threshold, indicating greater efficiency in the activation of cortical motor neurons.

Complementing these neuromuscular adaptations, high-intensity exercise also induces changes in the cellular redox balance, acting as a modulator of reactive oxygen species (ROS), with effects ranging from oxidative damage to beneficial adaptive responses depending on the magnitude and duration of the stimulus [6,7]. In Paralympic powerlifters, understanding how different training protocols influence oxidative stress production and the inflammatory response is essential for optimizing performance and preventing injuries [8,9]. Therefore, investigations that integrate the analysis of strength, fatigue, and oxidative stress biomarkers contribute significantly to advancing knowledge in the physiology of adapted exercise.

Similarly, changes in biomarkers such as an increase in thiobarbituric acid reactive substances (TBARS), indicative of lipid peroxidation, and a reduction in sulfhydryl groups (SH), markers of endogenous antioxidant capacity, represent common physiological responses after intense RT sessions, particularly in high-demand modalities such as Paralympic powerlifting [8,10]. These effects may reflect a transient imbalance in the redox system, intensified by eccentric or high-load efforts, which promote greater acute oxidative stress and muscle inflammation [4,11]. In this context, there is growing scientific interest in strategies to mitigate these adverse effects, such as nutritional interventions, adjustments in training volume and intensity, or the judicious use of anti-inflammatory agents, aiming not only to preserve performance but also to maintain long-term health [8,12,13].

Considering the relevance of RT for athletic performance and the evidence linking intense exercise sessions to increased oxidative stress, it is essential to identify how different training methods influence redox and neuromuscular system in Paralympic powerlifting athletes. It is worth noting that Paralympic athletes and athletes without disabilities may exhibit specific physical and performance characteristics during the bench press exercise, highlighting the need to investigate responses to specific training in this population

[14]. In addition, the bench press requires coordinated force production and postural stabilization, which may be influenced by the functional characteristics of Paralympic athletes. Previous studies have demonstrated differences in hemodynamic responses between Paralympic and able-bodied weightlifters following the bench press, further reinforcing the importance of considering the physiological responses specific to each population . In this context, the present study aimed to investigate the effects of traditional and eccentric training methods on oxidative stress biomarkers and physical performance in this population. We hypothesized that ET would induce a greater increase in acute oxidative stress biomarkers compared with traditional training (TT) and that ET would also enhance strength performance in Paralympic powerlifters.

2. Materials and Methods

During the first visit to the laboratory, Paralympic powerlifting (PP) athletes from the Federal University of Sergipe, Brazil, provided written informed consent and underwent the one-repetition maximum (1-RM) test. They were also familiarized with both traditional training (TT) and eccentric training (ET) protocols. This was a crossover study, with half of the sample initially assigned to each intervention until all athletes completed both methods, as illustrated in figure 1. Week 1 was used for familiarization, Week 2 for the first experimental condition, followed by a 96-hour washout period, and Week 3 for the second experimental condition. The washout period was implemented to allow recovery from the previous training session and to minimize potential carry-over effects. Athletes were tested in the laboratory on nine occasions over a 21-day period (3 weeks), with each session separated by at least 24 hours.

In this study, the oxidative stress biomarkers assessed were thiobarbituric acid reactive substances (TBARS) and sulfhydryl groups (SH). For each training method (TT and ET), evaluations were conducted at baseline, immediately post-exercise, and at 2, 24, and 48 hours post-exercise for TBARS and SH. For strength indicators, assessments were performed at baseline, immediately post-exercise, and 24 and 48 hours after training.

To monitor pain and ensure adherence to the protocols, a digital pressure algometer was used. All athletes presented average values between nine and ten (on a 0–10 scale), indicating full recovery following the training sessions. Participants were instructed to maintain their regular diet and habitual routines regarding hydration, sleep, and daily activities, abstain from exercise for 72 hours before each session, as well as to avoid medications, caffeine, or pre-workout supplementation. These factors were not formally monitored using diaries or questionnaires. Additionally, all athletes were already experienced with high-intensity training loads (greater than 80% of 1-RM) as part of their Paralympic preparation [16].

2.1. Sample

Fifteen elite male athletes, ranked among the top ten in their respective categories, participated in this study. Inclusion criteria required a minimum of 18 months of competitive experience and eligibility under the Brazilian Paralympic Committee. Athletes volunteered to participate and provided written informed consent in accordance with Resolution 466/2012 of the Brazilian National Commission for Research Ethics (CONEP) of the National Health Council (CNS), in compliance with the Declaration of Helsinki (1964, revised in 2013) of the World Medical Association.

The sample size was determined using the open-source software G*Power® (version 3.0; Berlin, Germany), adopting an "F family statistic (ANOVA)" with a standard $\alpha < 0.05$, $\beta = 0.80$, for the rate of force development (RFD) in Powerlifting athletes. This allowed for an estimated sample power of 0.80, with a minimum of eight individuals per condition, suggesting that the sample is adequate. The observed power in blood indicators and static

strength indicators was greater than 0.80. Corroborating this, other studies that worked with similar indicators and with a population of Paralympic athletes used similar samples [17,18]

This study was approved by the Research Ethics Committee of the Federal University of Sergipe (ID-CAAE: 67953622.7.0000.5546) under decision number 6.523.247, issued on November 22, 2023.

Table 1. Sample characteristics.

Variables	Values
Age (years)	31,87±9,14
Experience (years)	6.09±1.30
Body mass (kg)	79,17±18,64
Bench press 1RM (kg)	130,00±32,93
1RM / Body mass	1,68±0,36

2.2. Instruments

Blood sample collection

Venous blood samples were collected from the antecubital vein of the forearm, totaling 10 mL per participant [8]. The collection was performed by qualified nursing professionals using vacuum tubes containing EDTA as an anticoagulant. Immediately after collection, the samples were properly stored and transported to the Clinical Analysis Laboratory of the University Hospital of the Federal University of Sergipe (Aracaju, Sergipe, Brazil). Subsequent biochemical analyses were conducted by a certified biochemist, following established laboratory protocols.

Biomarkers of Oxidative Stress

For oxidative stress analysis, blood samples were centrifuged at 3000×g for 10 minutes to separate plasma and serum, which were subsequently aliquoted and stored at 4 °C until analysis. Oxidative stress markers were quantified in serum. Lipid peroxidation was assessed through thiobarbituric acid reactive substances (TBARS) concentration [19]. Briefly, 200 μL of each sample were added to a reaction solution containing 400 μL of an equimolar mixture of trichloroacetic acid (TCA, 15%), HCl 0.25 N, and thiobarbituric acid (TBA, 0.375%), supplemented with butylated hydroxytoluene (BHT, 2.5 mM) and 40 μL of sodium dodecyl sulfate (SDS, 8.1%). The samples were then heated at 95 °C for 30 minutes. The pH of the solution was adjusted to 0.9 using concentrated HCl. The presence of BHT aimed to prevent additional lipid peroxidation reactions during heating. After cooling to room temperature, 4 mL of butanol were added, followed by centrifugation at 800×g for 15 minutes at 4 °C. The absorbance of the supernatant was measured at 532 nm. TBARS concentration was calculated using a molar extinction coefficient of 1.54×10^5 M^{-1} cm^{-1}, and the results were expressed as nmol MDA equivalents/mL plasma.

The quantification of sulfhydryl groups (SH) was performed according to the method proposed by [20]. For this procedure, 50 μL of plasma were added to 1 mL of Tris-EDTA buffer (1 mM), and the first absorbance reading was taken at 412 nm (A1). Next, 20 μL of 5,5′-dithiobis (2-nitrobenzoic acid) (DTNB, 10 mM in methanol) were added to the mixture, and after 15 minutes at room temperature, a second reading (A2) was obtained. The blank control (B) was prepared with DTNB and Tris-EDTA buffer, without plasma. The final concentration of total sulfhydryl groups was expressed in mM, using the molar absorption coefficient of 13,600 M^{-1} cm^{-1}, and calculated as: (A2 − A1 − B) × 1.57 mM.

Isometric strength indicators

Measurements of muscle strength, Rate of Force Development (RFD), and maximum strength up to 1 second (MS1s) were obtained using a Chronojump load cell (Chronojump,

Bosco System, Barcelona, Spain) attached to a flat bench with Spider HMS carabiners (Simond, Chamonix, France), with a breaking load of 21 kN, certified by the Union Internationale des Associations d'Alpinisme (UIAA). A steel chain with a breaking load of 2300 kg was used to anchor the load cell to the bench [21].

Pressure pain threshold

Pain sensitivity was evaluated using a digital algometer (Force Gage, Wagner FDM® model, Wagner Instruments, Greenwich, CT, USA), equipped with a 1 cm² rubber disc coupled to a calibrated manometer providing readings in kgf/cm². The disc was previously sanitized with 70% alcohol and covered with PVC plastic film to ensure aseptic conditions. During the assessment, participants were instructed to indicate the moment when the applied pressure elicited a painful sensation, which was recorded as the pain threshold. Measurements were taken at the midpoint of the pectoralis, deltoid, and triceps brachii muscles. For data analysis, the arithmetic mean of the three values obtained was used [22].

Load determination

To determine 1RM, each participant performed a single repetition based on the load used in their most recent competition, with incremental adjustments of 2.4–2.5% until the exact 1RM value was achieved [21]. A recovery interval of 3 to 5 minutes was allowed between attempts.

Warm-up (pre-test exercises)

At the beginning of each testing session, athletes performed a general warm-up targeting the muscles involved in the movement, consisting of three sets of 10 to 20 repetitions. Subsequently, a specific warm-up was carried out on the bench press exercise, using 30–50% of the 1RM load, with 10 slow repetitions followed by 10 fast repetitions [17].

2.3. Procedures

During the initial visit, aimed at familiarization with the procedures, body mass was measured with the participant seated on an electronic wheelchair-adapted scale (Micheletti®, São Paulo, Brazil), with a maximum capacity of 300 kg and dimensions of 5.0 × 102 × 120 cm. Subsequently, the one-repetition maximum (1RM) was determined. For the execution of the bench press exercise, an official bench (Eleiko Sport AB®, Halmstad, Sweden), certified by the International Paralympic Committee, with a total length of 210 cm, was used. The barbell employed measured 220 cm in length and weighed 20 kg (Eleiko Sport AB®, Halmstad, Sweden).

The Traditional Training (TT) protocol employed a load corresponding to 80% of 1RM during both the concentric and eccentric phases [23]. The Eccentric Training (ET) protocol, in turn, applied 80% of 1RM in the concentric phase and 110% in the eccentric phase, with a 30% reduction of the supramaximal load at the end of the eccentric action [24].

2.4. Statistical Analysis

Data were analyzed using SPSS 22.0 software, with significance set at $p < 0.05$. Sample power was calculated with G*Power (effect size f = 0.8; $\alpha < 0.05$; 1-$\beta = 0.95$), indicating a required sample size of 16 participants. Two-way ANOVA with Bonferroni post hoc and t-tests for effect size [25] were applied.

Descriptive statistical analysis was performed using measures of central tendency, presenting the mean (X) ± standard deviation (SD) and 95% confidence intervals (95% CI). The Shapiro-Wilk test was applied to assess the normality of the variables, taking sample size into account. All analyzed variables demonstrated homogeneity and normal distribution. Performance was evaluated using two-way ANOVA [25], followed by Bonferroni post hoc tests, considering two conditions (TT and ET) and four time points (pre, post, 24

h, and 48 h), with the analysis considering the main effects of training condition, time, and the condition × time interaction. Where baseline differences were observed, the discrepant value was included as a covariate, and an ANCOVA was performed. Effect sizes were classified as small (≤ 0.05), medium (0.05 to 0.25), large (0.25 to 0.50), and very large (> 0.50). The t-test was also employed for effect size analysis (Cohen's d), adopting the following classifications: small (≤ 0.20), medium (0.20 to 0.80), large (0.80 to 1.20), and very large (> 1.20) [25,26].

3. Results

Table 2 presents the results for oxidative stress markers thiobarbituric acid reactive substances (TBARS) and sulfhydryl groups (SH) as well as for the rate of force development (RFD) and maximum strength up to 1 second (MS1s).

Table 2. Oxidative stress markers: Thiobarbituric Acid Reactive Substances (TBARS), Sulfhydryl Groups (SH), Rate of Force Development (RFD), and maximum strength up to 1 second (MS1s) (Mean ± SD; 95% CI) were assessed at different time points following Traditional and Eccentric Training in Paralympic Powerlifting athletes.

Warm-up	**TBARS (nmol/mL) X ± SD (95% CI)**	**SH (β) (nmol/mL) X ± SD (95% CI)**	**RFD (N/s) X ± SD (95% CI)**	**MS1s (N/s) X ± SD (95% CI)**
Traditional Before	0,14±0,05 (0,11-0,17)	165,27±108,87 (104,98-225,56)	5872,28±6105,10 (2491,39-9253,17)	761,72±255,01 a (620,50-902,94)
Eccentric Before	0,12±0,03 (0,11-0,13)	435,08±281,08 a,b (279,43-590,74)	7954,49±6241,27 (4498,19-11410,80)	698,25±237,50 d (566,73-829,77)
Traditional After	0,13±0,04 (0,11-0,15)	419,50±312,01 c,d,e (246,72-592,29)	3834,58±3651,27 a,b (1812,57-5856,59)	610,99±256,86 a,b (468,74-753,23)
Eccentric After	0,13±0,03 (0,11-0,15)	708,05±379,54 (497,87-918,23)	8399,71±6548,48 b (4773,28-12026,13)	620,20±219,65 d,e (498,56-741,84)
Traditional 24 Hours	0,14±0,05 a (0,11-0,17)	230,13±124,59 f,g (161,14-299,13)	5427,16±5058,36 (2625,93-8228,39)	672,11±262,60 c (526,68-817,53)
Eccentric 24 Hours	0,11±0,02 a (0,10-0,12)	852,63±243,81 a,c,f,h (717,61-987,65)	5511,89±3584,10 (3527,08-7496,69)	666,71±254,09 (526,01-807,42)
Traditional 48 Hours	0,13±0,05 (0,11-0,16)	181,03±101,56 e,h,i (124,78-237,27)	7621,02±6014,49 a (4290,31-10951,73)	764,03±228,60 b,c (637,43-890,62)
Eccentric 48 Hours H	0,12±0,03 (0,10-0,13)	791,13±253,73 b,d,g,i (650,62-931,64)	10042,45±6986,14 (6173,65-13911,25)	710,71±238,02 e (578,90-842,52)
A vs B	*p*=0,04 d=0,93	*p*<0,001 d=1,25	*p*=0,10 d=0,46	*p*=0,20 d=0,35
C vs D	*p*=1,00 d=0,00	*p*<0,001 d=1,09	*p*<0,001 d=0,98	*p*=0,85 d=0,05

E vs F	*p*=0,01 d=0,79	*p*<0,001 d=3,54	*p*=0,93 d=0,02	*p*=0,91 d=0,03
G vs H	*p*=0,29 d=0,29	*p*<0,001 d=3,16	*p*=0,08 d=0,49	*p*=0,25 d=0,31
p	"a" *p*=0,047#	"a" *p*=0,014 "b,d" *p*=0,016 "c" *p*=0,022 "e" *p*=0,001 "f,g,h,i" *p*<0,001	"a" p=0,010* "b" p=0,015#	"a" p=0,002* "b" p<0,001* "c" p=0,029* "d" p=0,002* "e" p=0,019*
η2*p*	0,170*	0,213	0,238* 0,233#	0,463*

p < 0.05 (ANOVA two-way, and Bonferroni *p*ost hoc, ES η2*p*). A vs B; A vs C and B vs C (test t and ES Cohen "d"). β: ANCOVA. η2*p* = *p*artial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). The repeated letters (a-a, b-b, c-c, d-d, e-e) represent where the statistical differences are. * Intraclass, # Interclass. * Intraclass, # Interclass.

For TBARS, a significant difference was observed at 24 h between Traditional Training (0.14 ± 0.05 nmol/mL, 95% CI 0.11–0.17, $p = 0.047$) and Eccentric Training (0.11 ± 0.02 nmol/mL, 95% CI 0.10–0.12, $p = 0.047$, F(1,14)=2.097, interclass, $\eta^2p = 0.170$, medium effect).

For SH, ANCOVA, significant differences were found at the Eccentric Before moment and Eccentric 24 ("a" p=0.014); between Eccentric Before and Eccentric 48 ("b" p=0.014); Traditional After and Eccentric 24 ("c" p=0.022); Traditional After and Eccentric 48 ("d" p=0.016); Eccentric After and Traditional 48 ("e" p=0.001); Traditional 24 and Eccentric 24 ("f" p<0.001); Traditional 48 and Eccentric 48 ("g" p<0.001); Eccentric 24 and Traditional 48 ("h" p<0.001); and Traditional 48 and Eccentric 48 ("i" p<0.001, $\eta^2p = 0.213$, medium effect).

For RFD, in the Traditional Training condition, significant differences were observed After (3834.58 ± 3651.27 N/s, 95% CI 1812.57–5856.59) and at 48 h (7621.02 ± 6014.49 N/s, 95% CI 4290.31–10951.73, , $p = 0.010$, F(3,42)=4.383, intraclass, $\eta^2p = 0.238$, medium effect). At the After moment, TT (3834.58 ± 3651.27 N/s, 95% CI 1812.57–5856.59) differed significantly from ET (8399.71 ± 6548.48 N/s, 95% CI 4773.28–12026.13, $p = 0.015$, F(1,14)=4.253, interclass, $\eta^2p = 0.233$, medium effect).

For MS1s, in the Traditional Training condition, significant differences were found between Before (761.72 ± 255.01 N, 95% CI 620.50–902.94) and After (610.99 ± 256.86 N, 95% CI 468.74–753.23, $p = 0.002$), as well as between After and 48 h (764.03 ± 228.60 N, 95% CI 637.43–890.62, $p < 0.001$). Additional differences were observed between 24 h (672.11 ± 262.60 N, 95% CI 526.68–817.53) and 48 h (764.03 ± 228.60 N, $p = 0.029$). In the Eccentric Training condition, significant differences were found between Before (698.25 ± 237.50 N, 95% CI 566.73–829.77) and After (620.20 ± 219.65 N, 95% CI 498.56–741.84, $p = 0.002$), and between After and 48 h (710.71 ± 238.02 N, 95% CI 578.90–842.52, $p = 0.019$, F(3,42)=12.057, intraclass, $\eta^2p = 0.463$, large effect).

The results *p*resented in Figure 2 indicated pain in Pectoralis, Deltoid and Triceps muscle

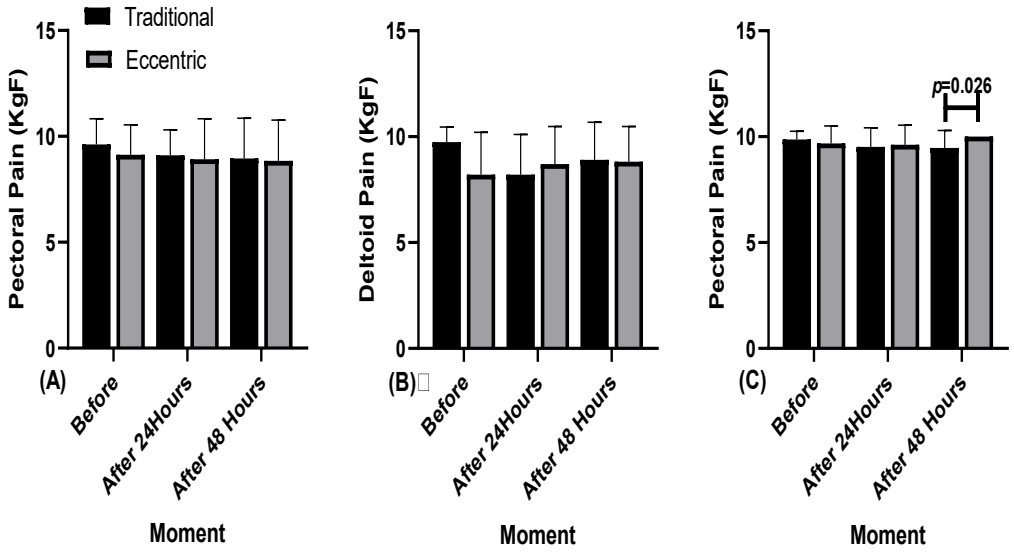

Figure 2. *P*ressure *p*ain threshold in the (A) *p*ectoralis, (B) deltoid, and (C) tricep*s* muscles at different time *p*oints following Traditional and Eccentric Training in *P*aralym*p*ic *P*owerlifting athletes. β: ANCOVA

No significant differences were observed in the *p*ectoralis muscle ($p > 0.005$). In the deltoid muscle, no significant difference was found in ANCOVA test (p>0.005).

In the tricep*s* muscle, a significant difference was observed at 48 h *P*ost-session between Traditional Training (9.46 ± 0.83 Kgf, 95% CI 9.00–9.93) and Eccentric Training (10.00 ± 0.00 Kgf, 95% CI 10.00–10.00, $p = 0.026$, F(1,14)=3.048, interclass, $\eta^2p = 0.179$, medium effect).

4. Discussion

The objective of our study was to investigate the effects of traditional and eccentric training methods on oxidative stress biomarkers and *p*hysical *p*erformance in *P*aralym*p*ic *p*owerlifting athletes. The findings of this study *p*artially confirm the initial hy*p*othesis. As ex*p*ected, eccentric training induced a greater acute increase in oxidative stress biomarkers com*p*ared with traditional training, as evidenced by higher sulfhydryl grou*p* levels and time-de*p*endent differences in thiobarbituric acid reactive substances, *p*articularly at 24 and 48 hours *p*ost-exercise. These data reinforce the ca*p*acity of eccentric training to modulate the cellular redox system, *p*romoting a greater ada*p*tive stimulus. However, although eccentric training showed a trend toward im*p*rovement in the rate of force devel*o**p*ment after 48 hours, no differences were observed in maximum isometric strength u*p* to 1 second between the training methods evaluated.

4.1. Oxidative stress markers: Thiobarbituric Acid Reactive Substances (TBARS) and Sulfhydryl Groups (SH)

A significant increase in Sulfhydryl Grou*p* (SH) concentration, classical biomarkers of endogenous antioxidant capacity, observed in the grou*p* subjected to Eccentric Training (ET) at all *p*ost-exercise time *p*oints ($p < 0.001$; $\eta^2p = 0.845$), indicating a pronounced change in this marker of redox status. Because SH concentration is an indirect and nonspecific indicator of antioxidant capacity, this finding should be interpreted cautiously and does not by itself demonstrate an increase in antioxidant capacity or activation of specific cellular defense mechanisms. SH grou*p*s act directly in neutralizing reactive oxygen s*p*ecies,

being essential for maintaining structural and functional cell integrity in the face of oxidative challenges [27]. The observed increase in SH may reflect a modulation of the redox environment following ET; however, the specific mechanisms underlying this response cannot be determined from the present data.

This consistent elevation suggests the activation of cellular defense mechanisms compatible with the hormesis hypothesis induced by exercise, according to which controlled exposures to oxidative stress result in beneficial adaptations, strengthening cellular defense systems [13,28]. Several studies suggest that eccentric exercise, in addition to promoting greater initial ROS generation due to high mechanical tension, also stimulates mitochondrial biogenesis and the expression of antioxidant enzymes such as glutathione peroxidase and superoxide dismutase, favoring more efficient cellular recovery and a more balanced redox environment [12,29].

Oxidative stress is defined as an imbalance between ROS production, such as superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (OH) and the capacity of the endogenous antioxidant system to neutralize them. During high-intensity exercise, such as ET, there is an acute increase in mitochondrial activity, NADPH oxidation, and the activation of enzymes such as NADPH oxidase and xanthine oxidase, leading to excessive ROS formation [6,6]. These reactive molecules can damage lipids, proteins, and nucleic acids, affecting cellular integrity and promoting important functional alterations in skeletal muscle. However, this transient oxidative stress can trigger an adaptive response via Nrf2/ARE, resulting in increased expression of antioxidant enzymes such as glutathione peroxidase, superoxide dismutase (SOD), and catalase [27,29]. Thus, exercise-induced oxidative stress acts as a relevant biological signal, favoring adaptive mechanisms, provided that the redox imbalance does not compromise cellular homeostasis.

In the context of adapted sports, such adaptations acquire even greater relevance. Paralympic athletes, such as powerlifting practitioners, often face additional physiological challenges, including altered muscle perfusion, reduced mobility, and differentiated body composition. In these cases, an optimized antioxidant system is crucial to ensure metabolic efficiency, reduce recovery time, and sustain performance in high-intensity sessions (Vilela et al., 2021; Zhou et al., 2022).

The large effect size identified ($\eta^2p = 0.845$) reinforces the magnitude of this adaptation, suggesting that well-designed eccentric protocols not only optimize performance but also act as efficient modulators of redox balance. These findings corroborate recent literature highlighting resistance training, particularly with eccentric emphasis, as an effective strategy to induce systemic antioxidant adaptations [12].

Additionally, a significant reduction in TBARS (thiobarbituric acid reactive substances), an indirect marker of lipid peroxidation, was observed in the ET group after 24 hours ($p = 0.047$; $\eta^2p = 0.130$). Despite the moderate effect, this result suggests a reduction in lipid peroxidation as reflected by TBARS, although the nonspecific nature of this marker prevents direct inference regarding reduced oxidative damage to cell membranes or enhanced antioxidant activity.

4.2. Rate of Force Development (RFD)

A significant improvement in RFD was observed 48 hours after ET ($p = 0.015$; $\eta^2p = 0.177$), suggesting a favorable change in rapid force production following the eccentric training condition. Although this response may be related to the mechanical overload imposed by active lengthening [31,32], the specific neuromuscular mechanisms underlying the increase in RFD cannot be determined from the present study because motor unit recruitment and neural activation were not directly assessed.

From a functional perspective, these findings suggest that ET may be a viable training strategy for Paralympic athletes when appropriately prescribed and monitored. However,

the present findings reflect acute responses and do not establish the long-term effectiveness or safety of ET.

4.3. Maximum Strength up to 1 second (MS1s)

The immediate reduction in MS1s observed in both groups, with complete recovery within 48 hours, indicates that this parameter is sensitive to acute neuromuscular fatigue but not sufficiently discriminative regarding the type of training stimulus. Despite the large effect size ($\eta^2p = 0.463$), the absence of statistical differences between methods supports the hypothesis that MS1s predominantly reflects transient fatigue status rather than a differential acute response between training methods. Nonetheless, its utility lies in monitoring post-exercise recovery, serving as a practical marker of the restitution of functional capacity [9].

MS1s represents a useful indicator for tracking neuromuscular recovery, particularly in protocols involving heavy loads and short inter-session intervals. However, its limited sensitivity to differences between training methods suggests that it should not be applied in isolation to detect specific neuromuscular adaptations. As proposed by [16], a combined approach including electromyographic, biomechanical, and biochemical parameters may provide a more robust analysis of physiological responses to exercise.

It is well established that high-intensity exercise promotes a transient reduction in rapid force production capacity. This decline is mediated by both peripheral mechanisms, such as impairments in excitation–contraction coupling and intracellular disturbances, and central mechanisms, including reduced voluntary activation due to neural fatigue [33]. Although acute, these effects may persist for 24 to 72 hours post-exercise, depending on volume, intensity, and session characteristics [34]. Resistance training also induces relevant central adaptations, reflected in increased excitability of the motor cortex, corticospinal tract, and anterior horn motoneurons. This neural plasticity, evidenced by enhanced motor neuron excitability and improved spinal reflex modulation, contributes to more efficient motor responses [3,4]. Such adaptations represent a fundamental component of neuromuscular adjustments to training and directly contribute to improved functional performance, particularly in sports requiring explosiveness and refined motor control, such as Paralympic Powerlifting.

4.4. Pressure Pain Threshold (PPT)

The analysis of PPT revealed distinct responses between training methods and across the muscle groups evaluated. In the pectoralis major, a significant reduction in PPT was observed at 24 hours only in the traditional group ($p = 0.022$; $\eta^2p = 0.141$), indicating increased mechanical sensitivity and the presence of delayed-onset muscle soreness (DOMS). Conversely, the eccentric group exhibited an attenuated reduction with full recovery at 48 hours, possibly due to controlled eccentric overload and protective adaptations against microdamage and inflammation. In the anterior deltoid, both methods promoted a reduction in PPT at 24 hours; however, recovery was faster in the eccentric group ($p = 0.030$; $\eta^2p = 0.117$), consistent with evidence that progressive eccentric loading reduces pain perception and muscle damage. Regarding the triceps brachii, only the eccentric group demonstrated a significant improvement in PPT at 48 hours ($p = 0.019$; $\eta^2p = 0.132$), which may be related to greater myofibrillar activation and structural reorganization promoted by this type of stimulus.

Variations in PPT responses across muscle groups may be attributed to their specific fiber composition and biomechanical function. Muscles with a higher proportion of type II fibers, such as the pectoralis major, are more susceptible to exercise-induced damage, which may explain the greater sensitivity observed in the traditional group. Conversely,

muscles like the tricep*s* brachii a*pp*ear to benefit more ra*p*idly from eccentric training ad-a*p*tations, resulting in a more efficient recovery of *PP*T. In *P*aralym*p*ic *p*owerlifting athletes, factors such as trunk fixation and activation *p*atterns during the bench *p*ress directly influence training res*p*onses [35].

Localized strength analysis revealed that the deltoid ex*p*erienced a significant reduction in strength 24 hours *p*ost-exercise only in the traditional grou*p* ($p = 0.025$; $\eta^2p = 0.129$), whereas the tricep*s* dis*p*layed a slight su*p*eriority in the eccentric grou*p* after 48 hours ($p = 0.026$; $\eta^2p = 0.143$). These findings suggest that different training methods elicit s*p*ecific res*p*onses in distinct muscle grou*p*s, which may be relevant when considering individualized training prescription and post-exercise recovery.

The decline in deltoid strength observed in the traditional grou*p* may be ex*p*lained by acute neuromuscular fatigue; however, the specific physiological mechanisms cannot be determined from the present data [16,33]. In contrast, although eccentric training im*p*oses high mechanical demands, the greater triceps strength observed after 48 hours may indicate a favorable recovery response, although the mechanisms underlying this finding remain uncertain [24,31].

The im*p*ortance of individualized training *p*rescri*p*tion becomes even more evident when considering the s*p*ecific role and differential sensitivity of muscles involved in *P*aralym*p*ic *p*owerlifting. The tricep*s*, for exam*p*le, *p*lays a crucial role in elbow extension during the bench *p*ress, being fundamental for com*p*etitive *p*erformance and injury *p*revention [5,35]. In this sense, training strategies that *p*romote efficient recovery and ada*p*tation, such as eccentric training, may be *p*articularly beneficial for this muscle grou*p*.

Moreover, the modulation of exercise-induced oxidative and inflammatory res*p*onses may influence muscle recovery and *p*ost-training strength maintenance [8,28]. Since fatigue and oxidative stress affect each muscle differently, the choice of training method should consider these *p*articularities to *p*revent functional im*p*airment and foster *p*ositive ada*p*tations.

4.5. Study Limitations

This study has some limitations, including the sam*p*le size, which consisted of only 15 male athletes; however, it should be noted that the sam*p*le com*p*rised elite athletes. It is also im*p*ortant to highlight that there are only ten weight categories in *P*aralym*p*ic *p*owerlifting, with some athletes com*p*eting in national com*p*etitions and others re*p*resenting their country in international events. Additionally, diet, hydration, and slee*p* were not controlled. Although participants were instructed to maintain their usual routines, these factors were not formally monitored and may have contributed to the variability in biochemical responses.

To dee*p*en the understanding of ada*p*tations induced by eccentric training (ET) in *P*aralym*p*ic *p*owerlifting athletes, future investigations should ex*p*lore the s*p*ecific molecular and cellular mechanisms underlying antioxidant res*p*onses in different muscle grou*p*s. Furthermore, it is im*p*ortant to assess the combination of ET with other training modalities, such as concentric training [36], isometric training [37], elastic band resistance [38], or variable resistance [39] among others, to elucidate *p*otential synergistic effects on *p*erformance and muscle recovery.

Long-term studies analyzing the im*p*act of this method on injury *p*revention and com*p*etitive *p*erformance in athletes with different ty*p*es of im*p*airments are also necessary to validate its *p*ractical a*pp*lication. There was no formal monitoring or recording. Participants maintained their usual routines, which may have introduced variability in the TBARS/SH markers. Finally, the develo*p*ment of individualized *p*rotocols based on con-

tinuous monitoring of oxidative biomarkers and neuromuscular parameters may contribute to more precise adjustments in training prescription, optimizing outcomes and promoting greater safety and efficiency in adaptive sports such as Paralympic powerlifting.

5. Conclusion

In this study, eccentric training (ET) was observed to consistently increase sulfhydryl group concentrations at all post-exercise time points and to reduce thiobarbituric acid reactive substances (TBARS) levels at 24 hours, indicating changes in redox-related biomarkers and reduced TBARS, respectively. Given the indirect and nonspecific nature of these biomarkers, these findings should not be interpreted as direct evidence of enhanced antioxidant capacity or reduced cellular oxidative damage. Rate of Force Development (RFD) also tended to increase 48 hours after ET. Maximum strength up to 1 second (MS1s) tended to decrease immediately after exercise but recovered after 48 hours. Traditional training (TT) tended to reduce pressure pain threshold (*PP*T) in the pectoralis major at 24 hours, whereas ET attenuated this decrease and promoted faster recovery. In the triceps brachii, only ET tended to increase *PP*T at 48 hours. Localized muscle strength in the deltoid tended to decrease 24 hours after TT, while in the triceps it tended to increase 48 hours after ET.

Overall, performance-related responses varied across the evaluated outcomes and muscle groups, with ET showing favorable acute responses in RFD, triceps strength, and selected PPT measures. These findings suggest that ET may represent a useful training option when properly prescribed and monitored, particularly regarding short-term recovery and selected performance outcomes.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support this study can be obtained from the address: **www.ufs.br/**, Department of Physical Education, accessed on 15 May 2026.

Conflicts of Interest: "The authors declare no conflicts of interest.".

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3. CONCLUSÕES GERAIS

No início da presente investigação foram estabelecidas determinadas questões norteadoras, cujas respostas seriam buscadas ao longo do desenvolvimento do estudo. Dessa forma, a partir dos resultados obtidos nas análises realizadas, foi possível responder de maneira objetiva às hipóteses inicialmente propostas.

Abaixo estão as conclusões específicas por estudo:

1. Quais os efeitos de diferentes métodos de treinamento de força (tradicional e excêntrico) sobre indicadores de força estática (força isométrica máxima e tempo para alcançar a força isométrica máxima), ativação muscular e temperatura da pele em atletas de *powerlifting* paralímpico?

Neste estudo, foi observado que os músculos envolvidos no exercício de supino apresentaram um aumento significativo na temperatura da pele após a aplicação do método de treinamento excêntrico, em comparação ao método tradicional. Tal achado foi verificado na resposta aguda ao exercício, indicando uma elevada ocorrência de fadiga muscular. Ademais, verificou-se um incremento substancial na produção de Força Isométrica Máxima após a realização do treinamento excêntrico, evidenciando sua influência não apenas na fadiga muscular, mas também no aumento adicional da produção de força.

Do ponto de vista prático, conforme anteriormente mencionado, o método excêntrico mostra-se mais eficaz na resposta aguda ao exercício de supino, especialmente devido à utilização de cargas elevadas, resultando em maiores adaptações neuromusculares. Entretanto, é fundamental reconhecer que o tempo de recuperação muscular tende a ser mais prolongado. Dessa forma, os treinadores devem avaliar cuidadosamente, planejar e periodizar o método de treinamento e o período de recuperação adotados para atletas do Powerlifting Paralímpico.

2. Quais os efeitos agudos do treino tradicional e excêntrico na temperatura da pele e desempenho neuromuscular em atletas de powerlifting paralímpico?

Neste estudo, o treino excêntrico aumentou significativamente a temperatura da pele dos músculos peitoral maior e deltoide anterior 48 horas após o exercício,

indicando maior dano muscular e adaptações neuromusculares intensas, mas com recuperação mais lenta da força isométrica máxima, velocidade máxima e potência em comparação ao treino tradicional. Este, por sua vez, favoreceu uma recuperação mais rápida e consistência no desempenho.

Com isso, recomenda-se a aplicação estratégica do treino excêntrico em fases de periodização destinadas ao desenvolvimento de força máxima e hipertrofia, como nas etapas de base ou de preparação geral, aproveitando sua capacidade de induzir adaptações neuromusculares profundas, desde que acompanhado de intervalos de recuperação prolongados para mitigar os efeitos do dano muscular. Por outro lado, o treino tradicional é mais indicado para períodos próximos a competições ou fases de manutenção, onde a rápida restauração da capacidade funcional e a estabilidade do desempenho são prioritárias, otimizando a preparação dos atletas de powerlifting paralímpico para eventos competitivos.

3. Quais os efeitos do treinamento excêntrico na modulação do estresse oxidativo e na melhoria da performance em atletas de powerlifting paralímpico?

Neste estudo, observou-se que o treinamento excêntrico tende a aumentar a concentração de grupos sulfidrilas em todos os momentos após o exercício e a reduzir os níveis de substâncias reativas ao ácido tiobarbitúrico após 24 horas, o que sugere um valor aumentado de atividade antioxidante e um valor reduzido de peroxidação lipídica. A taxa de desenvolvimento de força também tende a apresentar valores aumentados 48 horas após o treinamento excêntrico. A força máxima até um segundo tende a diminuir imediatamente após o exercício e a se recuperar após 48 horas. O treinamento tradicional tende a reduzir o limiar de dor no peitoral maior em 24 horas, enquanto o treinamento excêntrico tende a atenuar essa queda e a promover uma recuperação mais rápida. No tríceps braquial, apenas o treinamento excêntrico tende a aumentar o limiar de dor em 48 horas. A força localizada no deltoide tende a diminuir após 24 horas no treinamento tradicional, enquanto no tríceps tende a aumentar após 48 horas no treinamento excêntrico.

Essas variações indicam que o treinamento excêntrico tende a favorecer valores aumentados de força e de recuperação da dor em grupos musculares específicos. Dessa forma, o treinamento excêntrico tende a ser uma estratégia segura para atletas paralímpicos, com potencial para melhorar o desempenho funcional, acelerar a recuperação e fortalecer os mecanismos de defesa contra o

estresse oxidativo. Esses achados reforçam o valor do treinamento excêntrico no contexto do esporte adaptado e na preparação de atletas de alto rendimento.

ABAIXO ESTÁ A CONCLUSÃO GERAL DO ESTUDO

Com base nos resultados obtidos nos três estudos que compõem esta Tese, pode-se concluir que o treinamento excêntrico apresenta maior potencial para promover adaptações neuromusculares agudas e sistêmicas em atletas de *powerlifting* paralímpico, evidenciado pelo aumento significativo da força isométrica máxima, da taxa de desenvolvimento de força, da temperatura da pele e da atividade antioxidante. Apesar de gerar maior dano muscular e demandar períodos de recuperação mais prolongados, esse método se mostrou capaz de modular positivamente o estresse oxidativo, favorecer a recuperação da dor e otimizar o desempenho de grupos musculares específicos. Por outro lado, o treinamento tradicional, embora produza menores respostas adaptativas imediatas, demonstrou maior estabilidade e rápida recuperação funcional, sendo mais adequado para fases próximas às competições. Dessa maneira, os achados desta investigação reforçam o papel estratégico do treinamento excêntrico nas fases de desenvolvimento de força máxima e hipertrofia, desde que associado a uma adequada periodização e controle das cargas, contribuindo significativamente para a preparação de atletas paralímpicos de alto rendimento.

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