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TANISE PIRES MENDONÇA

EFEITOS AGUDOS DA OCITOCINA INTRANASAL SOBRE RESPOSTAS HORMONAIS, NEUROMUSCULARES E INDICADORES DE RECUPERAÇÃO EM ATLETAS DO *POWERLIFTING* PARALÍMPICO

SÃO CRITÓVÃO

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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

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À Universidade Federal de Sergipe.

Ao Programa de Pós-Graduação em Ciências Fisiológicas.

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“Sabemos que todas as coisas cooperam para o bem daqueles que amam a Deus, daqueles que são chamados segundo o seu propósito”.

(Bíblia Sagrada – Romanos 8: 28).

RESUMO

Efeitos agudos da ocitocina intranasal sobre respostas hormonais, neuromuscular e indicadores de recuperação em atletas do *Powerlifting* Paralímpico, Tanise Pires Mendonça, São Cristóvão, 2026.

O neuropeptídeo ocitocina envolvido na regulação do estresse, no metabolismo energético e em respostas sociais, tem sido estudado como um potencial modulador fisiológico das respostas ao treino. O objetivo desse estudo foi investigar os efeitos agudos da administração intranasal de ocitocina sobre respostas hormonais, neuromusculares, bioquímicas e térmicas associadas ao desempenho e à recuperação após uma sessão de treinamento de força em atletas do Powerlifting Paralímpico. O estudo foi realizado em 3 semanas e adotou um delineamento intra-sujeito, duplo-cego, randomizado e controlado por placebo, com 11 paratletas. As sessões experimentais tiveram intervalo de uma semana entre elas. Antes da cada sessão de treino, os participantes autoadministraram o spray intranasal contendo o placebo ou a ocitocina (24 Ui), logo após foram iniciados os pré-testes de força dinâmica (45% de 1RM), coletas de sangue para dosagem dos hormônios (testosterona total e livre, cortisol) e do dano muscular (CK, LDH, AST e ALT) e de temperatura da pele nos principais músculos envolvidos no gesto motor da modalidade. Foi utilizado um protocolo de treino de 5 séries de 5 repetições com carga de 80% de 1RM, onde foi realizado o teste dinâmico de força. Imediatamente após o treino repetiram-se os testes, e nas 24h e 48h pós-treino também. Nas variáveis de força dinâmica, mediram-se a velocidade média propulsiva, velocidade máxima e potência. Os resultados mostraram que, na condição ocitocina, houve redução significativa do cortisol do pré para o pós-treino (9,52 ± 3,57 vs. 6,48 ± 2,07 µg/dL; *p* = 0,002) e recuperação após 24h (*p* = 0,039). No placebo, o cortisol também reduziu (*p* = 0,011), mas com padrão menos estável. Nas variáveis de força submáxima (45% de 1RM), a ocitocina preservou a potência pós-treino (613,73 W vs. 481,82 W; *p* = 0,024) e a VMax (1,38 m/s vs. 1,31 m/s; *p* = 0,040), demonstrando maior tolerância à fadiga. Sob carga máxima (80% de 1RM), a ocitocina apresentou desempenho superior na série 4 em VMax (0,73 m/s vs. 0,61 m/s; *p* = 0,030) e potência (564,55 W vs. 457,55 W; *p* = 0,030). Nos marcadores de dano muscular, observou-se redução mais rápida da LDH nas 24h e 48h pós-treino com ocitocina (356,64 ± 67,14 vs. 409,64 ± 86,52 U/L; *p* = 0,005 e 328,55 ± 60,58 vs. 393,82 ± 72,54 U/L; *p* = 0,001, respectivamente), além de menores elevações de CK. A termografia mostrou que o uso da ocitocina atenuou aumentos prolongados da temperatura cutânea, especialmente no tríceps braquial (31,20 ± 1,06°C vs. 32,52 ± 1,17°C; *p* = 0,003) e peitoral externo (32,50 ± 2,10°C vs. 33,42 ± 1,46°C; *p* = 0,017), sugerindo menor sobrecarga periférica. Nas condições analisadas, podemos concluir que a administração aguda de ocitocina intranasal pode atuar como modulador multifatorial das respostas ao treino, promovendo equilíbrio hormonal, preservação da força e potência, redução do dano muscular e melhora da recuperação térmica.

Palavras-chave: Ocitocina; *Powerlifting* Paralímpico; Indicadores de Desempenho; Recuperação.

ABSTRACT

Acute effects of Intranasal Oxytocin on Hormonal and Neuromuscular Responses and Indicators of Recovery in Paralympic Powerlifting Athletes, Tanise Pires Mendonça, São Cristóvão, 2026.

The neuropeptide oxytocin, involved in stress regulation, energy metabolism, and social responses, has been studied as a potential physiological modulator of training responses. The aim of this study was to investigate the acute effects of intranasal oxytocin administration on hormonal, neuromuscular, biochemical, and thermal responses associated with performance and recovery after a strength training session in Paralympic Powerlifting athletes. The study was conducted over 3 weeks and adopted a single-subject, double-blind, randomized, placebo-controlled design with 11 para-athletes. The experimental sessions were spaced one week apart. Before each training session, participants self-administered an intranasal spray containing either a placebo or oxytocin (24 IU). Immediately afterward, pre-tests of dynamic strength (45% of 1RM) were initiated, along with blood samples for hormone levels (total and free testosterone, cortisol), muscle damage (CK, LDH, AST, and ALT), and skin temperature measurements in the main muscles involved in the motor gesture of the sport. A training protocol of 5 sets of 5 repetitions with a load of 80% of 1RM was used, during which the dynamic strength test was performed. The tests were repeated immediately after training, and again at 24 and 48 hours post-training. The dynamic strength variables measured included average propulsive speed, maximum speed, and power. The results showed that, under oxytocin conditions, there was a significant reduction in cortisol from pre- to post-workout (9.52 ± 3.57 vs. 6.48 ± 2.07 µg/dL; $p = 0.002$) and recovery after 24h ($p = 0.039$). In the placebo group, cortisol also decreased ($p = 0.011$), but with a less stable pattern. In submaximal strength variables (45% of 1RM), oxytocin preserved post-workout power (613.73 W vs. 481.82 W; $p = 0.024$) and VMax (1.38 m/s vs. 1.31 m/s; $p = 0.040$), demonstrating greater fatigue tolerance. Under maximum load (80% of 1RM), oxytocin showed superior performance in series 4 in VMax (0.73 m/s vs. 0.61 m/s; $p = 0.030$) and power (564.55 W vs. 457.55 W; $p = 0.030$). In muscle damage markers, a faster reduction in LDH was observed at 24h and 48h post-training with oxytocin (356.64 ± 67.14 vs. 409.64 ± 86.52 U/L; $p = 0.005$ and 328.55 ± 60.58 vs. 393.82 ± 72.54 U/L; $p = 0.001$, respectively), in addition to smaller elevations in CK. Thermography showed that the use of oxytocin attenuated prolonged increases in skin temperature, especially in the triceps brachii (31.20 ± 1.06°C vs. 32.52 ± 1.17°C; $p = 0.003$) and external pectoralis major (32.50 ± 2.10°C vs. 33.42 ± 1.46°C; $p = 0.017$), suggesting less peripheral overload. Under the conditions analyzed, we can conclude that acute intranasal oxytocin administration may act as a multifactorial modulator of training responses, promoting hormonal balance, preservation of strength and power, reduction of muscle damage, and improvement of thermal recovery.

Keywords: Oxytocin; Paralympic Powerlifting; Performance Indicators; Recovery.

RESUMO PARA A SOCIEDADE

Efeitos agudos da ocitocina intranasal sobre respostas hormonais, neuromuscular e indicadores de recuperação em atletas do *Powerlifting* Paralímpico, Tanise Pires Mendonça, São Cristóvão e 2026.

O esporte paralímpico tem crescido muito nas últimas décadas, exigindo que os atletas alcancem níveis cada vez mais altos de desempenho e recuperação. No entanto, encontrar estratégias seguras que ajudem na melhora da força, da resistência e na redução da fadiga continua sendo um grande desafio. Nesta pesquisa, investigamos o papel da ocitocina, um hormônio naturalmente produzido pelo corpo humano, conhecido por suas funções ligadas à confiança, ao vínculo social e ao controle do estresse, como possível aliada no desempenho esportivo. O estudo foi realizado com atletas de elite do Powerlifting Paralímpico, uma modalidade de levantamento de peso. Cada atleta participou de duas sessões de treino intenso: em uma delas recebeu ocitocina intranasal (em forma de spray) e, na outra, um placebo (sem substância ativa). Foram analisadas diferentes respostas do organismo, como hormônios relacionados ao estresse e à força, níveis de fadiga muscular, temperatura corporal e marcadores sanguíneos de recuperação. Os resultados mostraram que a ocitocina ajudou a equilibrar os hormônios do estresse, preservou a força e a potência muscular após o treino, e reduziu os sinais de dano e inflamação nos músculos. Além disso, os atletas que receberam ocitocina apresentaram melhor recuperação térmica, ou seja, o corpo mostrou sinais de recuperação mais rápida nas regiões musculares mais exigidas durante o exercício. Essas descobertas indicam que a ocitocina pode atuar como um modulador natural das respostas do corpo ao exercício, favorecendo o desempenho e a recuperação dos atletas, sem representar risco à saúde. O estudo contribui para ampliar o conhecimento sobre estratégias ergogênicas seguras e eficazes, que possam influenciar positivamente o equilíbrio entre desempenho e recuperação. Além de ampliar o entendimento sobre o campo da Fisiologia do Exercício e do Esporte Paralímpico.

Palavras-chave: Esporte Paralímpico; Força Muscular; Suplementação; Ocitocina; Desempenho; Recuperação**.**

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LISTA DE ABREVIATURAS E SIGLAS

C – Cortisol

CPB – Cômite Paralímpico Brasileiro

DA – Deltóide anterior

ELISA – Enzyme-Linked Immunosorbent Assay

HPA – Hipotálamo-hipófise-adrenal

HPG – Hipotálamo-hipófise-gonadal

IPC – International Paralympic Committee

OXTR – Receptor de ocitocina

PC – Peitoral clavicular

PE – Peitoral external

PKC – Proteína quinase C

PLC – Fosfolipase C

PP – *Powerlifting* Paralímpico

RM – Repetição Máxima

S1 – Primeira série

S2 – Segunda série

S3 – Terceira série

S4 – Quarta série

S5 – Quinta série

TB – tríceps braquial

TL – Testosterona Livre

TT – Testosterona Total

VMax – Velocidade Máxima

VMP – Velocidade Média Propulsiva

W – Potência

SUMÁRIO

1 – INTRODUÇÃO GERAL

1.1 – Treinamento de Força

A produção de força muscular durante o treinamento de força (TF) é um processo complexo e multifatorial que envolve uma integração precisa entre os sistemas neuromuscular, esquelético e metabólico. Em nível celular, a força é gerada pela interação entre as proteínas contráteis actina e miosina dentro do sarcômero — a menor unidade funcional da fibra muscular. Esse processo é iniciado pela liberação de íons cálcio (Ca^{2+}) do retículo sarcoplasmático, que se ligam à troponina, provocando uma alteração conformacional no complexo troponina-tropomiosina e expondo os sítios de ligação da actina. As cabeças de miosina então se ligam à actina, utilizando a energia proveniente da hidrólise da adenosina trifosfato (ATP), o que permite o deslizamento dos filamentos finos sobre os espessos, resultando no encurtamento da fibra muscular e na produção de força (Brooks et al., 2023; Mendoza et al., 2023; Frontera & Ochala, 2015).

Além dos processos intrínsecos à fibra muscular, a produção de força é modulada por fatores neurais, como recrutamento de unidades motoras e taxa de disparo, bem como por características mecânicas externas, como comprimento do músculo e velocidade de contração. As adaptações neurais durante o treinamento resistido incluem redução do limiar de recrutamento e aumento da frequência de disparo das unidades motoras (Quinlan et al., 2021; Bohm et al., 2015; Škarabot et al., 2021; Del Vecchio et al., 2019; Duchateau et al., 2006). Adicionalmente, adaptações no tecido conjuntivo são determinantes na eficiência de transmissão de força: o treinamento de força induz aumentos na rigidez do tendão e melhorias em suas propriedades elásticas, contribuindo para uma melhor transferência de força do músculo para o esqueleto (Bohm et al., 2015; Quinlan et al., 2021).

O treinamento de força, fundamentado nesses princípios de adaptação neuromuscular e estrutural, constitui um dos pilares da preparação física em diversas modalidades esportivas. Seu propósito central é aumentar a capacidade de gerar tensão muscular contra uma resistência externa, promovendo melhorias na força máxima, na hipertrofia, na potência e na resistência muscular localizada (Bird et al., 2005; Bosco et al., 2000). Ao estimular simultaneamente mecanismos neurais, musculares e endócrinos, esse tipo de treinamento favorece tanto o desempenho quanto a recuperação funcional, sendo amplamente empregado em contextos de alto rendimento e reabilitação (Kraemer & Ratamess, 2004). O avanço da ciência aplicada ao treinamento de força tem permitido compreender de forma mais integrada os múltiplos fatores que modulam o desempenho, a fadiga e os processos de recuperação dos atletas (Theofilidis et al., 2018). Dessa forma, o treinamento de força emerge não apenas como ferramenta de desenvolvimento da capacidade física, mas também como um potente estímulo fisiológico que induz adaptações sistêmicas e sustentáveis ao longo do tempo.

As respostas fisiológicas ao treinamento de força são agudas e crônicas, sendo que, em curto prazo, ocorrem alterações na excitabilidade neural e recrutamento de unidades motoras e sincronização entre elas, enquanto, em longo prazo, ocorrem mudanças morfológicas, como hipertrofia das fibras musculares, aumento da síntese proteica e maior eficiência neuromuscular (Schoenfeld, 2010); (Aagaard, 2003). A magnitude dessas respostas depende da manipulação de variáveis como volume, intensidade, frequência e tempo de recuperação entre as sessões (Ratamess et al., 2009).

Apesar dos efeitos positivos, o treinamento de força intenso e frequente pode levar a redução temporária da capacidade de desempenho muscular, ou seja, da instalação de fadiga muscular, especialmente quando há um volume ou intensidade de treino elevado, com recuperação insuficiente (Meeusen et al., 2013). A fadiga pode ser resultante de fatores centrais (como a redução da ativação cortical) e periféricos (como o acúmulo de metabólitos e depleção de substratos) (Enoka & Duchateau, 2008). Apesar da fadiga ser um componente necessário do treinamento, pois sua indução controlada estimula mecanismos de supercompensação e adaptação, o prolongamento desse estado pode comprometer o desempenho físico e aumentar o risco de lesões.

Do ponto de vista fisiológico, a fadiga está associada a alterações nos potenciais de ação musculares, na liberação de cálcio no retículo sarcoplasmático, na regulação da via AMPK/mTOR e em alterações hormonais como o aumento do cortisol e diminuição da testosterona durante o exercício de alta intensidade (Ahtiainen et al., 2003). A compreensão da fadiga é essencial para o planejamento do treinamento, uma vez que sua acumulação excessiva pode gerar overreaching ou overtraining (Meeusen et al., 2013).

Diante do exposto, entendemos que os hormônios desempenham papel central na mediação das adaptações fisiológicas ao exercício físico, atuando como mensageiros químicos que regulam processos como crescimento tecidual, metabolismo energético, resposta inflamatória e recuperação pós-exercício (Hackney & Elliott-Sale, 2021). No contexto do treinamento físico, os principais hormônios de interesse são a testosterona, com ação predominantemente anabólica, e o cortisol, de natureza catabólica, cuja interação influencia diretamente o equilíbrio muscular e a performance (B. T. Crewther et al., 2011a). No exercício de resistência, níveis elevados de testosterona total e livre estão associados a melhores respostas hipertróficas e neuromusculares (B. T. Crewther et al., 2011a) (B. Crewther et al., 2006). Em contrapartida, o cortisol é liberado em resposta ao estresse físico ou psicológico, promovendo efeitos catabólicos como a mobilização de aminoácidos, degradação proteica, inibição da síntese de proteínas musculares e aumento da gliconeogênese hepática (Kraemer & Ratamess, 2005). Embora o cortisol tenha funções adaptativas importantes, como a manutenção da homeostase, sua elevação crônica pode comprometer o anabolismo muscular e aumentar a susceptibilidade à fadiga (Chourpiliadis & Aeddula, 2025); (Braun & Marks, 2015).

Além dos hormônios como meios de avaliar o treinamento, há crescente interesse em indicadores dinâmicos de força, como a velocidade média propulsiva (VMP), a velocidade máxima (VMax) e a potência (W), que refletem, de maneira prática e sensível, a integridade neuromuscular e o grau de desempenho e fadiga funcional. Em protocolos com cargas altas, essas variáveis tornam-se particularmente sensíveis à fadiga neuromuscular, que se expressa por perdas na velocidade máxima e na potência, mesmo com menor volume de repetições. A VMP representa a média das velocidades durante a fase propulsiva do movimento, estando diretamente relacionada ao esforço voluntário do sistema neuromuscular e à fadiga acumulada. A VMax reflete a maior velocidade atingida durante a execução do gesto, sendo particularmente sensível à ativação motora e à integridade das unidades motoras de recrutamento rápido. Já a potência, produto entre força e velocidade, representa uma métrica composta, integrando tanto a capacidade de produzir força quanto de aplicá-la rapidamente (Sánchez-Medina & González-

Badillo, 2011). Esses parâmetros vêm sendo utilizados como ferramenta para ajustar a carga de treino em tempo real e para avaliar os efeitos de intervenções ergogênicas sobre o desempenho (González-Badillo & Sánchez-Medina, 2010).

Em paralelo, novos biomarcadores de estresse fisiológico e recuperação vêm sendo explorados. A termografia infravermelha, por exemplo, permite avaliar alterações térmicas superficiais da pele associadas à perfusão sanguínea, inflamação e sobrecarga muscular, representando uma ferramenta complementar não invasiva no monitoramento da fadiga e do dano muscular (DE Almeida Barros et al., 2020). Após a exposição a uma sobrecarga mecânica, observa-se tipicamente aumento da temperatura cutânea local na região muscular exercitada, resultado do aumento da perfusão sanguínea e da atividade metabólica associada ao exercício. Essas alterações são detectadas por meio de mudanças no padrão térmico superficial. Entretanto, quando a diferença térmica cutânea local em relação ao valor basal ou à região contralateral ultrapassa aproximadamente 1,6°C, esse padrão pode indicar maior estresse tecidual e possível aumento do risco de lesão musculoesquelética (Marins et al., 2015).

Da mesma forma, enzimas como creatina quinase (CK), lactato desidrogenase (LDH), alanina aminotrasnferase (ALT) e aspartato aminotransferase (AST) servem como indicadores bioquímicos indiretos de microlesões musculares induzidas pelo exercício, especialmente úteis para estimar o grau de dano tecidual e o tempo necessário para a recuperação completa. Dentre as enzimas plasmáticas, a CK é a mais específica no diagnóstico do dano muscular. A atividade sérica dessas enzimas (CK, LDH, ALT e AST) é considerada um bom indicador da função muscular em condições fisiológicas e patológicas (Brancaccio et al., 2007)

1.2 – *Powerlifting* e *Powerlifting* Paralímpico

Dentre as modalidadesas esportivas, a mais exigente é o *Powerlifting*, que requer elevadas demandas neuromusculares para a execução dos três movimentos competitivos — agachamento, supino e levantamento terra, nos quais os atletas devem levantar a maior carga possível em uma única repetição (Zourdos et al., 2016). Esse esporte demanda níveis elevados de força máxima, coordenação motora, estabilidade articular e controle neuromuscular. Diferente do treinamento de força convencional, o *Powerlifting* é altamente específico, sendo caracterizado por intensidades de carga próximas a 90–100% do 1RM (uma repetição máxima), longos intervalos de descanso e baixo volume de repetições por série (Austin & Mann, 2020). Essa especificidade exige uma preparação sistemática e a manipulação estratégica das variáveis de treino, como periodização, seleção de exercícios acessórios e monitoramento da recuperação.

No cenário paralímpico, o *Powerlifting* é adaptado exclusivamente ao levantamento de supino, realizado em uma posição específica com critérios técnicos e classificatórios rigorosos, que representa um importante espaço de inclusão esportiva e expressão da força máxima entre atletas com deficiências físicas (Loturco et al., 2013; (*Para Powerlifting Rules and Regulations*, s. d.). Essa especificidade impõe particularidades biomecânicas relevantes, como maior demanda dos músculos peitorais e tríceps braquiais, menor contribuição da cadeia posterior e ausência de participação ativa dos membros inferiores, o que altera o padrão de produção de força e a distribuição das cargas mecânicas durante o exercício. Ademais, atletas com deficiência física podem apresentar respostas fisiológicas atípicas ao treinamento e à recuperação, incluindo alterações no recrutamento neuromuscular, na resposta autonômica, no perfil hormonal e nos processos de fadiga e recuperação muscular, em função do tipo e nível da deficiência (Loturco et al., 2013). Dessa forma, os estímulos de força em atletas paralímpicos devem ser aplicados de maneira altamente específica e individualizada, considerando suas limitações e potencialidades, com o objetivo de otimizar a performance (Gołaś et al., 2017; Bird et al., 2005).

A singularidade dos atletas paralímpicos de força não se restringe apenas às adaptações biomecânicas impostas por suas condições clínicas, as quais variam amplamente de acordo com o tipo e o nível da deficiência, mas também envolve respostas neuromusculares e hormonais específicas decorrentes do treinamento de alta intensidade. Evidências indicam que determinados grupos de atletas, especialmente aqueles com lesões neurológicas ou motoras, podem apresentar alterações no tônus muscular basal, na composição corporal e nos perfis hormonais em repouso, influenciando a resposta ao treinamento (Buhmann et al., 2024); (Gołaś et al., 2017). À medida que o status de treinamento evolui, a regulação de hormônios endógenos, como testosterona e cortisol, assume papel central na capacidade de resposta à carga e no desenvolvimento de força máxima, o que pode desafiar modelos tradicionais de periodização. Por exemplo, atletas com lesão medular cervical apresentam padrões específicos de variação de testosterona e cortisol durante sessões agudas e ao longo de meses de treinamento contínuo, distintos daqueles observados em atletas sem deficiência (Stieler et al., 2022). Além disso, atletas com lesões medulares ou deficiências motoras podem apresentar uma maior prevalência de fadiga central, associada à menor eficiência neuromuscular e menor recrutamento de unidades motoras (Jacobs & Nash, 2004). Nessas circunstâncias, o monitoramento individualizado da carga e da prontidão fisiológica torna-se não só recomendável, mas essencial, já que a fadiga neuromuscular e os desequilíbrios hormonais podem comprometer o desempenho e elevar o risco de lesões (Häkkinen, 1989).

No contexto de múltiplas interações fisiológicas, o controle da fadiga, do dano muscular e da recuperação no *Powerlifting* Paralímpico é determinante para o sucesso competitivo e a manutenção da saúde do atleta. Por isso, o interesse por estratégias ergogênicas seguras e eficazes tem se tornado cada vez maior, especialmente aquelas que possam influenciar positivamente o ambiente hormonal e o equilíbrio entre desempenho e recuperação.

1.3 – Suplementação Ergogênica e sua importância

No cenário multifatorial, a suplementação ergogênica tem sido amplamente utilizada como estratégia auxiliar no desempenho esportivo, na recuperação pós-treino e atenuação dos efeitos deletérios da fadiga induzida pelo treinamento intenso. Tais recursos, quando devidamente aplicados, podem influenciar vias metabólicas e neuroendócrinas relevantes para o desempenho físico, além de otimizar adaptações ao treinamento de força (Maughan et al., 2018). Os suplementos podem atuar por diferentes mecanismos, como melhora na ressíntese de ATP, aumento da disponibilidade de substratos energéticos, modulação do sistema nervoso central, tamponamento da acidose muscular, ou ainda por efeitos hormonais e neuromusculares (Kerksick et al., 2018). Sua eficácia, entretanto, depende de fatores como o tipo de exercício, dose, tempo de uso, perfil fisiológico do atleta e o momento da ingestão em relação à sessão de treino.

Dentre os suplementos clássicos temos creatina, cafeína e beta-alanina, com eficácia já bem estabelecida em relação à melhora da performance e à atenuação da fadiga (Kerksick et al., 2018). A creatina monohidratada é um dos suplementos mais bem estudados e eficazes no contexto do Treinamento de Força. Sua principal ação ergogênica está relacionada ao aumento da disponibilidade de fosfocreatina intramuscular, facilitando a ressíntese de ATP durante esforços de alta intensidade e curta duração (Kreider et al., 2017). A cafeína, por sua vez, é um suplemento com ação primariamente no sistema nervoso central, atuando como antagonista dos receptores de adenosina. Esse mecanismo promove maior excitação neural, redução da percepção de esforço, aumento da liberação de catecolaminas e melhora da contração muscular voluntária (Grgic et al., 2018). A beta-alanina, por sua vez, atua como um precursor da carnosina, substância que tampona os íons H+, retardando a acidose muscular e permitindo maior volume de treino. Além disso, os aminoácidos de cadeia ramificada (BCAAs) têm sido utilizados com o objetivo de atenuar a degradação proteica e a dor muscular de início tardio; entretanto, evidências recentes indicam que seus efeitos isolados sobre recuperação muscular, dor e desempenho são limitados e inconsistentes, especialmente quando a ingestão proteica total é adequada, o que coloca em questão sua real eficácia ergogênica em protocolos de treinamento de força (Li et al., 2024); (Wolfe, 2017).

1.4 – A Ocitocina como Possível Suplemento nos Esportes de Força

Além dos suplementos clássicos, substâncias neuromoduladoras têm despertado interesse no contexto esportivo por seu potencial de influenciar variáveis centrais relacionadas ao desempenho, como o estado hormonal, a percepção de esforço e a resposta ao estresse fisiológico (Kerksick et al., 2018). Entre essas substâncias emergentes destaca-se a ocitocina, um neuropeptídeo sintetizado no hipotálamo e liberado pela neuro-hipófise, com ampla atuação nos sistemas neuroendócrino, imune e comportamental (La Fratta et al., 2021; Mottolese et al., 2014; Torner et al., 2017).

Embora tradicionalmente associada ao parto e à lactação (Burt et al., 1963) e à regulação de comportamentos sociais e emocionais, evidências acumuladas demonstram que a ocitocina também exerce papel relevante na modulação de respostas fisiológicas ao estresse e na homeostase metabólica. Esses efeitos ocorrem por meio de mecanismos centrais e periféricos envolvendo a ativação do receptor de ocitocina (OTR), um receptor acoplado à proteína G amplamente distribuído no sistema nervoso central e em tecidos periféricos. A ligação da ocitocina ao OTR ativa a cascata da fosfolipase C, resultando na formação de inositol trifosfato (IP_3) e diacilglicerol (DAG), com consequente mobilização intracelular de cálcio (Ca^{2+}) e ativação da proteína quinase C. Essa sinalização desencadeia respostas fisiológicas integradas que incluem modulação autonômica, regulação neuroendócrina, efeitos analgésicos centrais e alterações na perfusão periférica (Gimpl & Fahrenholz, 2001; Mottolese et al., 2014).

No sistema nervoso central, a ocitocina atua em regiões como a amígdala, hipotálamo e tronco encefálico, estruturas envolvidas na regulação da resposta ao estresse, da percepção de dor e da integração neuroendócrina. Uma das principais ações fisiológicas da ocitocina ocorre por meio da modulação do eixo hipotálamo-hipófise-adrenal (HPA), reduzindo a liberação de corticotropina (CRH) no hipotálamo e atenuando a secreção de cortisol em situações de estresse psicofisiológico (Carter, 2014; Heinrichs et al., 2003). Essa modulação do eixo HPA pode contribuir para um ambiente hormonal mais favorável à recuperação após o exercício, uma vez que níveis elevados de cortisol estão associados ao aumento do catabolismo proteico e ao comprometimento da recuperação muscular. Esses mecanismos sugerem que a ocitocina pode exercer efeitos indiretos sobre o desempenho esportivo e os processos de recuperação após o esforço (Jurek & Neumann, 2018; Zingg & Laporte, 2003).

Além de seus efeitos sobre o eixo HPA, evidências sugerem que a ocitocina pode interagir com o sistema androgênico, influenciando indiretamente a dinâmica hormonal associada ao exercício físico. Embora os mecanismos ainda não estejam completamente esclarecidos, estudos indicam que a ocitocina pode participar da regulação do equilíbrio entre hormônios anabólicos e catabólicos, contribuindo para a manutenção da homeostase hormonal em situações de estresse fisiológico intenso (Carter, 2014).

Outro mecanismo potencialmente relevante no contexto esportivo envolve os efeitos da ocitocina sobre a fadiga muscular e a percepção de esforço. A ação da ocitocina em regiões cerebrais associadas à regulação emocional e sensorial pode modular a percepção subjetiva de esforço e a tolerância à dor durante exercícios intensos. Esse efeito analgésico central, aliado à modulação da resposta ao estresse, pode contribuir para maior tolerância ao esforço físico e melhor manutenção do desempenho em atividades de alta intensidade (Uvnäs-Moberg et al., 2014; Cardoso et al., 2013).

Além dos efeitos centrais, a ocitocina também exerce influência sobre processos fisiológicos periféricos relacionados à recuperação muscular. Estudos experimentais indicam que a ativação do receptor de ocitocina pode estimular mecanismos envolvidos na regeneração muscular, incluindo a ativação de células satélites e a modulação de vias inflamatórias associadas ao reparo tecidual. Em modelos murinos, a ativação do sistema ocitocinérgico foi associada à melhora da regeneração muscular e à preservação da força após dano muscular, sugerindo um possível papel da ocitocina nos processos adaptativos do músculo esquelético (Elabd et al., 2014).

Outro aspecto relevante envolve a regulação autonômica e cardiovascular mediada pela ocitocina. Estudos em humanos demonstram que a ocitocina pode aumentar o tônus parassimpático e reduzir a atividade simpática, favorecendo maior variabilidade da frequência cardíaca e melhor capacidade de recuperação após estressores físicos ou psicológicos (Kemp et al., 2012). Essa modulação autonômica pode influenciar diretamente a perfusão periférica e a redistribuição do fluxo sanguíneo durante e após o exercício. Alterações na perfusão periférica podem se refletir em mudanças na temperatura da pele detectadas por termografia infravermelha. A ocitocina apresenta efeitos vasodilatadores e pode modular a circulação periférica por meio da interação com o sistema nervoso autônomo e mediadores endoteliais, influenciando potencialmente a dinâmica térmica da pele após o exercício. Essas alterações podem estar associadas à redistribuição do fluxo sanguíneo e aos processos de recuperação muscular após esforços físicos intensos (Xu et al., 2022).

A administração de ocitocina por via intranasal tem sido investigada principalmente em estudos experimentais com humanos, geralmente em doses agudas entre 24 e 40 UI, demonstrando efeitos como modulação positiva do humor, redução da reatividade ao estresse, menor percepção subjetiva de esforço e maior tolerância à dor, sobretudo em contextos de estresse psicofisiológico e tarefas desafiadoras (Savaskan et al., 2008), aspectos que podem favorecer tanto o desempenho quanto a recuperação no Treinamento de Força. Embora seu uso ainda seja incipiente no contexto esportivo, uma revisão sistemática recente indicou que o próprio exercício físico é capaz de estimular a liberação endógena de ocitocina, sugerindo um potencial papel desse neuropeptídeo na recuperação e na resiliência fisiológica após o exercício (Szabó et al., 2024).

Estudos com modelos experimentais em animais e estudos celulares indicam que a ocitocina pode estar envolvida em processos relacionados à regeneração e adaptação muscular. Em modelos murinos, a ativação do receptor de ocitocina foi associada à melhora da regeneração muscular e à preservação da força, possivelmente por interação com vias anabólicas e mecanismos de reparo tecidual, especialmente em condições de envelhecimento ou dano muscular (Elabd et al., 2014). Dessa forma, a ocitocina emerge como uma substância de interesse no contexto esportivo por atuar predominantemente em mecanismos centrais, modulando dor, cognição, emoção e controle autonômico, configurando uma abordagem distinta dos ergogênicos tradicionais, que atuam majoritariamente sobre fatores periféricos, como metabolismo energético ou fluxo sanguíneo muscular (Szabó et al., 2024).

Apesar dos potenciais benefícios, o uso da ocitocina como suplemento ainda exige cautela, especialmente por se tratar de um hormônio com múltiplas ações fisiológicas e psicológicas. Aspectos relacionados à dose, frequência, efeitos colaterais e variabilidade interindividual permanecem pouco esclarecidos, demandando maior número de estudos controlados em populações atléticas, inclusive em atletas com deficiência física (Gossen et al., 2012). Além disso, uma limitação relevante discutida na literatura refere-se à controvérsia sobre a eficácia da via intranasal em promover concentrações biologicamente significativas de ocitocina no sistema nervoso central humano, uma vez que mecanismos como difusão direta pelo nervo olfatório ou transporte axonal ainda não estão completamente elucidados (Leng & Ludwig, 2016; Cardoso et al., 2013; Coiro et al., 1988).

A suplementação deve ser entendida como parte de uma estratégia integrada de otimização do desempenho, que inclui treino estruturado, alimentação adequada, sono reparador e monitoramento da fadiga. Em atletas paralímpicos, cujas respostas fisiológicas podem ser atípicas devido à condição neuromuscular, a suplementação ergogênica pode ter papel ainda mais relevante na manutenção da performance e na prevenção de sobrecarga (Bauermann et al., 2022; Shaw et al., 2021; Graham-Paulson et al., 2015).

Portanto, a compreensão dos mecanismos fisiológicos envolvidos na ação da ocitocina, bem como a personalização de sua aplicação, é essencial para maximizar os benefícios e minimizar riscos. O avanço das investigações sobre compostos como a ocitocina oferece promissora contribuição para o campo da fisiologia do exercício e para o aprimoramento do desempenho no treinamento de força, inclusive em modalidades como o *Powerlifting* Paralímpico.

1.5 – Questões de Estudo

No contexto do *Powerlifting* Paralímpico, observa-se com frequência uma discrepância entre o desempenho apresentado em sessões de treinamento e aquele reproduzido em ambiente competitivo, mesmo quando as condições físicas e técnicas aparentam estar preservadas. Evidências da psicofisiologia do esporte sugerem que fatores emocionais, como medo, ansiedade antecipatória e ameaça percebida, podem comprometer a expressão máxima da força por meio da ativação exacerbada de circuitos centrais relacionados ao estresse, especialmente a amígdala cerebral e o eixo hipotálamo-hipófise-adrenal (HHA).

Embora esses mecanismos sejam amplamente reconhecidos em contextos clínicos e psicobiológicos, ainda são pouco explorados no treinamento de força adaptado, particularmente no que diz respeito à interação entre estados emocionais, respostas hormonais, desempenho neuromuscular e recuperação fisiológica. Nesse cenário, a ocitocina emerge como um neuropeptídeo de interesse, uma vez que apresenta efeitos bem documentados sobre a modulação do medo, do estresse, da dor e do controle autonômico, além de influenciar o ambiente hormonal associado ao desempenho físico.

Apesar desse potencial teórico, permanecem lacunas relevantes quanto aos efeitos da ocitocina sobre variáveis fisiológicas integradas em modelos de treinamento de força, especialmente em populações paralímpicas, cuja fisiologia adaptativa e carga psicossocial diferem substancialmente de atletas sem deficiência.

Diante desse cenário, o presente estudo buscou responder às seguintes questões de pesquisa:

1. A administração aguda de ocitocina intranasal modula as respostas hormonais (testosterona total, testosterona livre e cortisol), neuromusculares (velocidade média propulsiva, velocidade máxima e potência) e térmicas (temperatura cutânea por termografia) após uma sessão de treinamento de força de alta intensidade em atletas do *Powerlifting* Paralímpico?

2. A administração aguda de ocitocina intranasal influencia o desempenho neuromuscular em cargas elevadas (80% de 1RM) e os marcadores bioquímicos de dano muscular (CK, LDH, AST e ALT), contribuindo para a preservação do desempenho e para os processos de recuperação em atletas do *Powerlifting* Paralímpico?

A escolha por investigar essas questões justifica-se pela necessidade de aprofundar o conhecimento sobre estratégias que integrem aspectos centrais e periféricos do desempenho e da recuperação em atletas paralímpicos, considerando não apenas a carga mecânica do treinamento, mas também os fatores emocionais e neuroendócrinos que modulam a expressão da força. A identificação de intervenções seguras, acessíveis e fisiologicamente plausíveis representa uma contribuição relevante para a ciência do esporte adaptado, além de oferecer subsídios práticos para o monitoramento da prontidão ao treinamento por meio de múltiplos marcadores fisiológicos.

1.6 Hipóteses

Dessa forma, esta pesquisa partiu das seguintes hipóteses principais:

H0 – *A suplementação aguda de ocitocina intranasal não altera variáveis hormonais, de dano muscular, de temperatura da pele e de indicadores dinâmicos de força em atletas do Powerlifting Paralímpico submetidos ao Treinamento de Força de alta intensidade.*

H1 – *A suplementação aguda de ocitocina intranasal altera variáveis hormonais, de dano muscular, de temperatura da pele e de indicadores dinâmicos de força em atletas do Powerlifting Paralímpico submetidos ao Treinamento de Força de alta intensidade.*

Essas hipóteses representam uma abordagem inovadora ao propor uma ligação direta e testável entre a intervenção (ocitocina), e sua repercussão sobre os sistemas hormonal, neuromuscular, térmico e muscular esquelético, oferecendo uma nova perspectiva sobre como substâncias com propriedades neuromodulatórias podem ser incorporadas ao manejo do treinamento de força. Ao preencher essa lacuna, espera-se que o estudo amplie o entendimento sobre os mecanismos fisiológicos que sustentam o desempenho adaptado e contribua para o avanço da fisiologia aplicada ao esporte paralímpico. Para isso, dois estudos experimentais foram conduzidos, integrando variáveis objetivas de desempenho e marcadores fisiológicos de estresse e recuperação.

1.7 – Organização da Tese

A presente tese foi estruturada no formato Modelo de Artigos, composta por dois estudos experimentais, com o propósito de oferecer uma visão integrada sobre os efeitos agudos da administração intranasal de ocitocina no contexto do treinamento de força do *Powerlifting* Paralímpico. A opção por esse formato decorre da amplitude de dados coletados, da diversidade das variáveis analisadas e da complexidade das relações fisiológicas investigadas, o que exigiu uma abordagem segmentada e, ao mesmo tempo, convergente.

A perspectiva de organizar o trabalho em dois estudos independentes, porém interligados, fundamenta-se na intenção de contribuir para o avanço do conhecimento sobre estratégias ergogênicas seguras e eficazes aplicadas ao esporte paralímpico de alto rendimento. Além disso, buscou-se destacar a relevância das respostas hormonais, neuromusculares, bioquímicas e térmicas como indicadores integrados do desempenho e da recuperação no treinamento de força.

O **Estudo 1** – O efeito do uso de ocitocina intranasal associada ao treinamento de força sobre a testosterona, o cortisol, fadiga e a temperatura da pele em atletas do *Powerlifting* Paralímpico, pretendeu dar resposta a Questão 1. E foi dedicado à análise dos efeitos da ocitocina sobre as respostas hormonais (testosterona e cortisol), sobre a fadiga neuromuscular (indicadores de força dinâmica — VMP, VMax e potência com carga de 45% de 1RM) e sobre as respostas térmicas cutâneas avaliadas por termografia infravermelha, buscando compreender a modulação aguda promovida pela ocitocina durante uma sessão de treino.

O **Estudo 2** – Avaliação do uso de ocitocina intranasal em indicadores de força dinâmica e dano muscular em atletas do *Powerlifting* Paralímpico, pretendeu dar resposta a Questão 2. E concentrou-se na investigação dos efeitos da ocitocina sobre o desempenho neuromuscular em cargas elevadas (80% de 1RM) e sobre os marcadores bioquímicos de dano muscular (CK, LDH, AST e ALT), além de explorar as possíveis interações entre desempenho e integridade muscular, de modo a elucidar o papel potencial da ocitocina na preservação da força e na recuperação pós-esforço.

Dessa forma, no capítulo dois dessa tese estão descritos os estudos realizados no formato tradicional de artigo contendo: Resumo, Introdução, Métodos, Resultados e Discussão.

No capítulo três da tese estão às considerações finais e, por último, são apresentadas as conclusões gerais, procurando dar resposta às questões de estudo, sugerindo implicações práticas e novas linhas de investigação.

1.8 – Objetivos

1.8.1 – Objetivo Geral

Investigar os efeitos agudos da administração intranasal de ocitocina sobre respostas hormonais, neuromusculares, bioquímicas e térmicas associadas ao desempenho e à recuperação após uma sessão de treinamento de força em atletas do *Powerlifting* Paralímpico.

1.8.2 – Objetivos Específicos

- Comparar as respostas hormonais de testosterona total, testosterona livre e cortisol, após uma sessão de treino de força, entre as condições ocitocina e placebo.
- Analisar os parâmetros neuromusculares de velocidade média propulsiva, velocidade máxima e potência, com cargas de treino submáxima (45% de 1RM) e de alta intensidade (80% de 1 RM), após uso de ocitocina e placebo.
- Avaliar as alterações agudas em marcadores bioquímicos de dano muscular (CK, LDH, AST e ALT), numa sessão de treino de força, entre as condições ocitocina e placebo.
- Comparar os padrões de resposta térmica cutânea regional (supino) nas duas condições experimentais.

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2 ESTUDOS REALIZADOS

2.1 – ESTUDO 1: Effects of Intranasal Oxytocin Combined with Resistance Training on Testosterone, Cortisol, Fatigue, and Skin Temperature in Paralympic Powerlifting Athletes.

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2.1 – ESTUDO 1: Effects of Intranasal Oxytocin Combined with Resistance Training on Testosterone, Cortisol, Fatigue, and Skin Temperature in Paralympic Powerlifting Athletes

ABSTRACT

Background: Safe and effective ergogenic strategies remain a challenge in elite Paralympic sports. Oxytocin, a neuropeptide linked to stress regulation and energy metabolism, has emerged as a potential modulator of exercise responses.

Objective: To examine the effects of intranasal oxytocin on hormonal, neuromuscular, and thermal responses in Paralympic powerlifting athletes.

Methods: Eleven athletes completed a randomized, double-blind, placebo-controlled trial, performing a traditional strength session (5×5 at 80% 1RM). Total testosterone (TT), free testosterone (FT), cortisol, dynamic strength at submaximal load (45% 1RM), and skin temperature (thermography) were assessed.

Results: In the placebo condition, TT increased from post to 24h (310.18 → 394.18 ng/dL; p=0.024), while cortisol decreased from pre to post (10.07 → 6.72 µg/dL; p=0.011). Under oxytocin, cortisol fell acutely (9.52 → 6.48 µg/dL; p=0.002) with partial recovery at 24h (8.73 µg/dL; p=0.039). Oxytocin preserved velocity and power at 45% 1RM and attenuated prolonged skin temperature elevations in key muscles.

Conclusion: Oxytocin acted as a multifactorial modulator, enhancing hormonal balance, submaximal performance, and peripheral recovery, suggesting potential as an ergogenic aid in Paralympic powerlifting.

Keywords: Oxytocin; Paralympic Powerlifting; Athletic Performance; Muscle Fatigue; Recovery.

INTRODUCTION

Since 1906, when Sir Henry H. Dale first characterized oxytocin using posterior pituitary extracts to induce uterine contractions in cats, knowledge about this neuropeptide has expanded substantially (Liu & Conboy, 2017). Within the field of endocrinology, oxytocin has been shown to exert roles beyond its classical functions in reproduction and lactation, including social modulation, stress regulation, cognition, and cooperative behavior (Gimpl & Fahrenholz, 2001). More recently, evidence indicates that oxytocin contributes to skeletal muscle regeneration and delays age-related functional decline (Elabd et al., 2014), enhances lean mass in older adults with sarcopenic obesity (Espinoza et al., 2021), mediates the physiological benefits of exercise in cancer patients (Alizadeh et al., 2018), and influences key hormonal responses such as testosterone and cortisol secretion (Brown et al., 2016), these findings suggest that oxytocin may create a more favorable endocrine and metabolic environment to support physical performance.

In parallel, studies on hormonal responses to exercise have demonstrated that high-intensity strength protocols elicit acute fluctuations in testosterone and cortisol, representing anabolic and catabolic hormones, respectively. Exercise sessions that induce substantial levels of muscular fatigue (e.g., ~45% loss in dynamic strength) result in pronounced alterations in these hormonal markers. Heavy resistance training protocols, as well as combined modalities, typically lead to post-exercise increases in cortisol and subsequent reductions in testosterone during the hours that follow (S. Taipale & Häkkinen, 2013). These endocrine responses are closely associated with training adaptations—or, in some cases, overtraining—as well as with their downstream effects on muscle recovery, metabolic health, and physical performance.

Another relevant yet less frequently examined physiological component, particularly in conjunction with hormonal responses and fatigue, is skin temperature. During strength and endurance exercise, the redistribution of blood flow, sweating, and thermoregulatory adjustments lead to notable changes in skin temperature, which can serve as an indirect marker of exercise intensity and fatigue. Evidence indicates that skin temperature rises following resistance sessions and is modulated by factors such as load intensity, recovery duration, and body composition (de Souza Leite Júnior et al., 2025; Sillero-Quintana et al., 2022; Weigert et al., 2018). Moreover, movement velocity has been shown to influence thermal dynamics, suggesting that distinct contractile patterns may elicit differentiated thermal responses (Formenti et al., 2016). In strength athletes, particularly within Paralympic powerlifting, eccentric training has been associated with prolonged increases in skin temperature in specific muscle groups, potentially reflecting greater muscle damage and subsequent recovery processes (de Souza Leite Júnior et al., 2025). Therefore, skin temperature assessment through infrared thermography emerges as a valuable tool for monitoring fatigue, recovery, and adaptation to high-intensity training.

The selection of Paralympic Powerlifting athletes is justified not only by the competitive relevance of this sport, but also by the physiological, autonomic, and psychosocial particularities associated with the performance of athletes with physical disabilities. Evidence shows that this group presents a higher burden of chronic stress, altered patterns of autonomic regulation, a higher prevalence of persistent pain, and possible neuroendocrine adaptations resulting from both the disability itself and the demands of high-performance strength training (Bauman et al., 2011; Rosa et al., 2020). These factors make Paralympians a particularly relevant model for investigating neurohormonal modulators, such as oxytocin, whose effects on the HPA axis and on psychophysiological responses to stress are better established. Thus, rather than seeking a 'clear gap' in the literature, which is indeed limited, the present study is based on the need to understand how oxytocin can act in a group that faces multiple additional stressors and whose performance may be particularly sensitive to interventions that modulate stress, fatigue, and recovery. Integrating hormonal responses, markers of muscle fatigue, and thermal changes in an acute session of intense training therefore offers a relevant and innovative framework for investigating potential benefits of oxytocin in this specific sporting context.

Therefore, the aim of this study was to investigate the effects of intranasal oxytocin on hormonal responses (testosterone and cortisol), muscular fatigue, and skin temperature following a maximal strength training session in Paralympic powerlifting. We hypothesized that oxytocin would enhance the testosterone response, attenuate the excessive rise in cortisol, reduce the magnitude of muscular fatigue, and modulate skin temperature during recovery. Understanding these effects may contribute to the development of targeted interventions to optimize performance and recovery in athletes engaged in high-intensity training.

METHODOLOGY

Study design

The study was conducted over a three-week period and employed a within-subject, randomized, double-blind, placebo-controlled design (saline solution). During the first week, participants underwent familiarization with all experimental procedures. In the second week, random allocation determined whether each participant would receive the placebo or intranasal oxytocin condition, with 50% assigned to each. In the third week, the conditions were reversed, such that those who initially trained under the placebo condition subsequently trained under oxytocin, and vice versa.

Prior to the experiment, all labeling identifying the solution inside the vials was carefully removed to maintain blinding. Participants were instructed to fast for at least one hour before each training session and to refrain from consuming caffeine or alcohol on the day of testing (Gorka et al., 2015). Experimental sessions were separated by one week to allow for adequate washout. Participants self-administered one intranasal spray per nostril (24 IU/40.32 µg) of synthetic oxytocin or a placebo saline solution (both prepared by Pharma Manipulações, Sergipe, Brazil) (Carter, 2014). Immediately following oxytocin/placebo administration, pre-exercise data collection and the training session were initiated, lasting approximately 90 minutes. This timeframe is consistent with previous studies on intranasal administration and corresponds to the expected window of oxytocin's physiological effects (Carter, 2014).

The training protocol followed a 5×5 method, consisting of five sets of five repetitions performed at 80% of each participant's one-repetition maximum (1RM). Post-training assessments were conducted immediately after the session, with additional data collections performed 24 hours later. On the remaining days, participants were instructed to rest.

Weeks	**Day 1**			**Day 2 e 3**	**Other Days**
Week 1 Familiarization		Body Assessment 1RM Test		♿ Rest	♿ Rest
Week 2 (Supplementation 50% Placebo and 50% Oxytocin)	**Before** Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	**Intervention** **5x5 – 80% 1RM**	**After** Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	♿ Rest
Week 3 (Supplementation 50% Placebo and 50% Oxytocin)	**Before** Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	**Intervention** **5x5 – 80% 1RM**	**After** Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	Test Dynamic Strength 45% 1RM (encoder), Temperature, Blood Collection	♿ Rest

Figure 1. Experimental Design – Weekly Training Programming

Sample

The initial sample comprised 14 Paralympic powerlifting athletes enrolled in an extension program at the Federal University of Sergipe, Brazil, each with a minimum of 12 months of training experience. All participants were national-level competitors who met the eligibility criteria established by the Brazilian Paralympic Committee for participation in the sport (*Comitê Paralímpico Brasileiro*, 2025). However, three participants were excluded from the study, and their data removed from analysis, due to failure to complete all phases of data collection. The descriptive characteristics of the final sample are presented in Table 1.

All athletes participated voluntarily and provided written informed consent, in accordance with Resolution 466/2012 of the National Commission for Research Ethics (CONEP) of the Brazilian National Health Council, and in compliance with the ethical principles outlined in the Declaration of Helsinki. The study protocol was approved by the Research Ethics Committee of the Federal University of Sergipe (approval no. 2.637.882).

Table 1. Characterization of subjects

	(Mean±SD)
Age (years)	33,90±10,67
Body Weight (kg)	77,22±21,22
Experience (years)	4,40±1,78
1RM Bench Press Test (kg)	141,50±35,44*
1RM/Body Weight	1,91±0,52**

* All athletes with loads that keep them among the top 10 in their categories at the national level.
** Values above 1,4 in the Bench Press would be considered elite athletes (Ball & Weidman, 2018).

Instruments and Procedures

Participants' body mass was measured using a Michetti digital platform scale, which allows seated weighing, with a maximum capacity of 300 kg and dimensions of 1.50 × 1.50 m (Michetti, Brazil). For the bench press exercise, a flat bench, a standard barbell, and official Olympic weight plates (Eleiko, Halmstad, Sweden) were used, approved by *Internacional Paralympic Committee* (*Para Powerlifting Rules and Regulations*, s. d.).

The determination of the maximum load was performed using the one-repetition maximum (1RM) test during the familiarization week (week 1), following standardized procedures for experienced athletes. Initially, participants performed a specific warm-up consisting of progressive sets with submaximal loads (≈40%, 60%, and 80% of the estimated 1RM load) before maximal attempts. Then, the first attempt was performed with a load estimated based on the athlete's prior experience and recent competitive training records. Progressive load increments were then applied until the highest load correctly lifted in a single repetition was determined. If the participant was unable to complete the attempt, the load was reduced by approximately 2.4–2.5%, as recommended in the literature for fine-tuning in trained athletes (Fleck & Kraemer, 2004; (Kraemer & Ratamess, 2004). Recovery intervals of 3 to 5 minutes were observed between attempts. The 1RM test was conducted on two occasions, with a minimum interval of 72 hours before the experimental intervention, ensuring adequate familiarization and stability of the measurements.

Blood samples were collected from the antecubital vein of the forearm, using vacuum collection tubes containing clot activator gel, before, immediately after, and 24 hours post-workout. Blood samples were collected by a trained healthcare professional (a laboratory technician). The blood was left to stand for 30 minutes at room temperature, then centrifuged for 10 minutes to separate the serum. The samples were then stored and kept refrigerated in an ice-filled cooler, without direct contact with the ice, at approximately 8°C. After each day's collection, the samples were immediately sent to a reputable clinical analysis laboratory (Aracaju, Sergipe, Brazil), which handled the remaining analytical procedures.

The hormones were analyzed using the Chemiluminescence Method. Automated chemiluminescence assays generally demonstrate excellent analytical stability, especially platforms like Roche Elecsys (ECLIA), where intra-assay coefficients of variation (CVs) range from 2 to 5% and inter-assay CVs from 3 to 7%, according to manufacturer validation. It is important to note that all samples from each participant (baseline, post-assay, and 24h) were analyzed in the same analytical batch, thus minimizing variation between assays.

Blood collection occurred in the morning, when the circadian rhythm is less variable and more stable. Collections before and after training were performed at the same time (morning), so that the circadian rhythm equally affects both moments. The interval between collections was short, not long enough to generate the natural circadian decline that occurs throughout the day. We sought to standardize the times, that is, that the beginning and end of each athlete's collections did not exceed 1 hour and 30 minutes, so that we could compare the variations induced by training and supplementation (oxytocin), not the natural variation of the day. Therefore, baseline and 24-hour collections occurred between 8:00-9:00 AM.

The selection of blood sampling time points is justified by the fact that acute hormonal responses to exercise, particularly cortisol and testosterone, occur predominantly within the first few hours following exertion, typically returning to baseline levels within approximately 24 hours. Cortisol, for instance, generally peaks during or shortly after exercise (30–90 minutes) and gradually decreases over the subsequent hours, normalizing before 24 hours (Kraemer & Ratamess, 2005; Hackney, 2021). Therefore, extending the hormonal sampling period beyond 24 hours would likely capture already stabilized values, providing little additional insight into the acute recovery phase.

Additionally, studies on the kinetics of oxytocin in cerebrospinal fluid (CSF) following intranasal administration have shown that plasma concentrations rise rapidly, peaking at approximately 15 minutes and subsequently declining over roughly 75 minutes, whereas elevations in the CSF occur only after this period and do not directly correlate with plasma levels (Striepens et al., 2011a). This pattern indicates that the peripheral (blood) hormonal response is acute and short-lived, further supporting the notion that blood sampling beyond 24 hours would primarily capture normalized values, providing minimal additional insight into the acute recovery phase.

Dynamic strength data at 45% of 1RM were collected pre-exercise, immediately post-exercise, and at 24 and 48 hours post-exercise. At each time point, participants performed four repetitions of the bench press as fast as possible (Figure 2A). The measured variables included Mean Propulsive Velocity (MPV, m/s), Peak Velocity (Vmax, m/s), and Power (W), which were obtained using a linear position transducer (encoder) from Vitruve (Madrid, Spain) (Pérez-Castilla et al., 2019).

Skin temperature measurements were performed using thermographic imaging in a controlled room, without natural lighting and without directed airflow toward the measurement area. Ambient temperature was maintained at approximately 24°C, with relative humidity around 50%, controlled by air conditioning and monitored using a hygrometer (HIGHMED, model HM-01, USA).

For thermogram acquisition, participants were instructed to avoid vigorous physical activity in the 24 hours prior to testing and to refrain from applying any creams or lotions to the skin during the 6 hours immediately preceding the assessment. They were also asked to remain seated, avoid sudden movements, keep their arms uncrossed, and refrain from scratching for a minimum acclimation period of 10 minutes (DE Almeida Barros et al., 2020; Fernández-Cuevas et al., 2017).

Thermographic images were captured using a FLIR T640sc infrared camera, with a measurement range of 40°C to 2000°C, 2% accuracy, sensitivity < 0.035°C, infrared spectral band of 7.5–14 µm, a refresh rate of 30 Hz, and a resolution of 640 × 480 pixels. The camera was positioned perpendicular to the target area at a fixed distance of approximately 1 meter to ensure uniform coverage of the muscles of interest, following standardized guidelines for skin temperature assessment to minimize external influences (Formenti et al., 2016). Images were analyzed using FLIR TOOLS software (FLIR, Stockholm, Sweden). The regions of interest included the anterior surfaces of the pectoralis major, deltoid anterior, and biceps brachii, as well as the posterior surface of the triceps brachii.

Skin temperature measurements were performed pre-exercise, immediately post-exercise, and at 24 and 48 hours post-exercise, as changes in cutaneous temperature reflect not only immediate responses to exertion but also slower physiological processes such as local inflammation, blood flow redistribution, and tissue repair. Evidence indicates that following high-intensity exercise or exercise with a substantial eccentric component, surface temperature may remain altered for up to 48 hours—a period during which delayed onset muscle soreness (DOMS) and other markers of residual fatigue also manifest (Fernández-Cuevas et al., 2015). Therefore, extending the thermal assessment allowed monitoring of both acute responses and adaptations associated with the subacute phase of muscle recovery (Figure 2B).

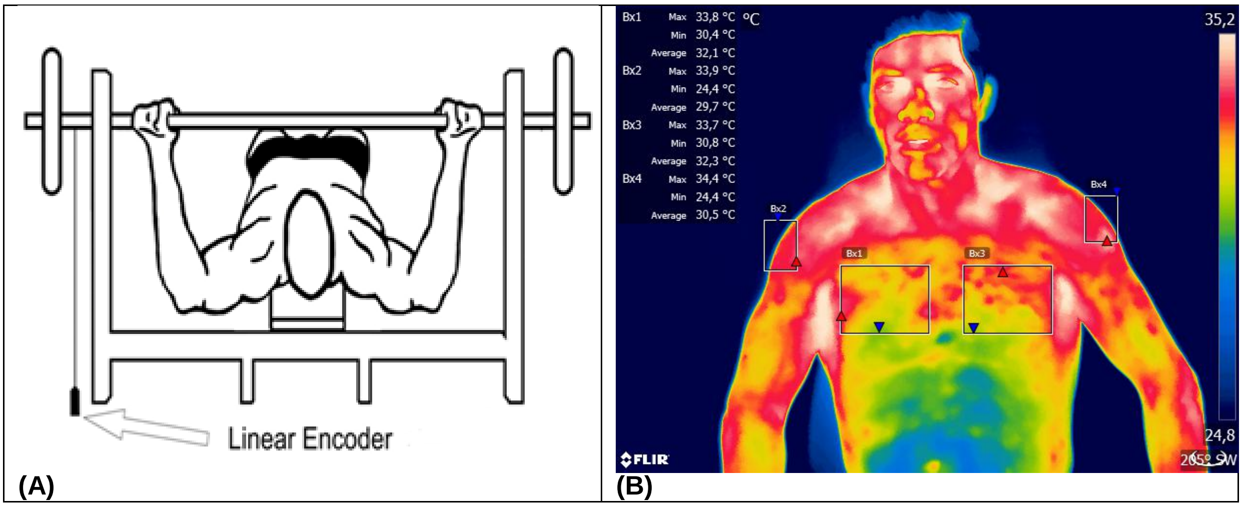

Figure 2. Detail of the placement of the linear encoder connected to the bar (**A**), and infrared thermography photo model (**B**).

Statistical Analysis

Central tendency measures, including the mean and standard deviation (X ± SD), as well as the 95% confidence interval (CI 95%), were utilized. Given the sample size, the Shapiro–Wilk test was conducted to verify the normality of the data. A two-way ANOVA (condition x moment) for repeated measures, followed by Bonferroni post hoc tests, was employed. The effect size was assessed using the partial eta squared (η^2_p), with magnitudes classified as low < 0.05, medium 0.05 to <0.25, high 0.25 to <0.50 and very high ≥0.50. (Cohen, 1992). Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS), version 24. A significance level of $p < 0.05$ was adopted for all analyses (IBM, New York, NY, USA).

RESULTS

Table 2 presents the mean values (Mean ± SD; 95% CI) of total testosterone (TT), free testosterone (FT), at different time points (pre-exercise, post-exercise, and 24 hours post-exercise) under the placebo and oxytocin conditions.

Table 2. Hormonal responses (Mean ± SD; 95% CI) at multiple time points during a 5×5 training session with oxytocin or placebo in Paralympic Powerlifting.

Condition	Time point	TT (ng/dL)	FT (ng/dL)	Cortisol (µg/dL)
Placebo	Before	379,08±146,14 (280,90-477,26)	7,63±2,28 (6,10-9,16)	10,07±3,72 a,b (7,57-12,57)
	After	310,18±108,74 a (237,13-383,23)	6,23±1,87 (4,97-7,49)	6,72±1,65 a (5,61-7,84)
	24hs	394,18±142,62 a (298,37-489,99)	7,64±3,04 (5,60-9,68)	8,08±3,17 b (5,95-10,21)
Oxytocin	Before	369,79±129,48 (282,80-456,77)	7,99±2,89 (6,05-9,93)	9,52±3,57 c (7,13-11,92)
	After	336,60±154,88 (232,55-440,64)	7,12±2,60 (5,38-8,87)	6,48±2,07 c,d (5,09-7,87)
	24hs	368,16±147,23 (269,25-467,07)	7,69±2,2 (6,16-9,21)	8,73±2,78 d (6,86-10,60)
p		“a” *p*=0,024	0,286	“a” *p*=0,011* “b” *p*=0,038* “c” *p*=0,002* “d” *p*=0,039*
F		4,707		13,403
η2p		0,320*		0,573*

(ANOVA two way and Post Hoc de Bonferroni). Identical superscript letters indicate statistically significant differences (p ≤ 0.05) (Ex: a-a, b-b), * intraclass (between moments – before, after and

24h), # interclass (between conditions – oxytocin/placebo); η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). TT – total testosterone; FT – free testosterone; C – cortisol.

Analysis of the training session at 80% of 1RM revealed that total testosterone (TT) increased between the post-exercise and 24-hour time points (p = 0.024), but only under the placebo condition. Cortisol decreased between pre- and post-exercise (p = 0.011) and pre-exercise and 24 hours post-exercise (p = 0.038) in the placebo condition. Under the oxytocin condition, cortisol decreased between pre- and post-exercise (p = 0.002) and increased between post-exercise and 24 hours (p = 0.039). Regarding the testosterone-to-cortisol ratio, an increase was observed between pre-exercise and 24 hours post-exercise (p = 0.046) in the placebo condition.

Table 3 presents the results of dynamic strength indicators, including mean propulsive velocity (MPV), peak velocity (VMax), and power (W), under oxytocin and placebo conditions, measured pre-exercise, post-exercise, and at 24 and 48 hours following a training session.

Table 3. Dynamic strength at 45% of 1RM (Mean ± SD; 95% CI) at multiple time points during a 5×5 training session with oxytocin or placebo in Paralympic Powerlifting.

Condition	Time point	VMP (m/s)	VMax (m/s)	Power (W)
Placebo	Before	0,95±0,25 (0,79-1,12)	1,40±0,27 a (1,22-1,58)	609,09±280,93 (420,36-797,82)
	After	0,90±0,24 (0,74-1,06)	1,31±0,26 c (1,14-1,49)	481,82±191,95 a (352,87-610,77)
	24hs	0,80±0,08 a (0,74-0,85)	1,12±0,10 a,d (1,05-1,19)	495,18±161,70 (386,55-603,81)
	48hs	0,83±0,08 (0,77-0,88)	1,15±0,11 (1,08-1,22)	506,09±144,57 (408,97-603,21)
Oxytocin	Before	0,95±0,25 (0,78-1,12)	1,39±0,28 (1,21-1,58)	609,64±276,53 (423,86-795,41)
	After	0,97±0,24 (0,80-1,13)	1,38±0,26 b,c (1,21-1,55)	613,73±239,75 a (452,66-774,41)
	24hs	0,74±0,07 a (0,69-0,79)	1,06±0,13 b,d (0,97-1,15)	470,36±121,45 (388,77-551,95)
	48hs	0,92±0,19 (0,79-1,04)	1,32±0,28 (1,13-1,51)	580,73±205,82 (442,45-719,00)
p		“a” *p*=0,042#	“a” *p*=0,043* “b” *p*=0,040* “c” *p*=0,024# “d” *p*=0,048#	“a” *p*=0,003#

F	3,975#	7,395* 4,974#	6,413#
η2p	0,284#	0,425* 0,332#	0,391#

(ANOVA two way and Post Hoc de Bonferroni). Identical superscript letters indicate statistically significant differences (p ≤ 0.05) (Ex: a-a, b-b), *Intraclass* differences: within-condition over time (*); *Interclass* differences: between conditions at the same time point (#); η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). VMP – average propulsive speed; Vmax – maximum speed; W – power.

Regarding the fatigue gradient (González-Badillo & Sánchez-Medina, 2010), the dynamic strength test at 45% of 1RM revealed an intergroup difference in MPV at the 24-hour time point (p = 0.024). For VMax, a decrease was observed between pre-exercise and 24 hours post-exercise (p = 0.043) under the placebo condition, and between post-exercise and 24 hours (p = 0.040) under the oxytocin condition. Intergroup differences were also noted at the post-exercise (p = 0.020) and 24-hour (p = 0.048) time points. Regarding power, an intergroup difference was observed only at the post-exercise time point (p = 0.003).

Table 4 presents skin temperature results for the Pectoralis Major – External (PE), Pectoralis Major – Clavicular (PC), Anterior Deltoid (DA), and Triceps Brachii (TB) regions, under oxytocin and placebo conditions, measured pre-exercise, post-exercise, and at 24 and 48 hours following the training session.

Table 4. Skin temperature (Mean±SD; 95% CI) at multiple time points during a 5×5 training session with oxytocin or placebo in Paralympic Powerlifting.

Condition	Time point	PE (°C)	PC (°C)	DA (°C)	TB (°C)
Placebo	Before	32,88±1,42 (31,98-33,78)	33,19±1,17 a (32,45-33,93)	33,43±,94 (32,84-34,03)	31,73±1,02 a (31,09-32,38)
	After	33,39±1,97 (32,14-34,65)	34,01±1,40 (33,12-34,90)	33,78±1,27 (32,98-34,59)	32,38±1,39 (31,49-33,26)
	24hs	33,75±1,53 (32,78-34,72)	34,41±0,93 a,b (33,82-35,00)	34,05±,95 (33,44-34,65)	32,52±1,17 a,d (31,78-33,26)
	48hs	33,42±1,46 a (32,49-34,35)	33,68±1,27 (32,87-34,48)	33,57±,84 (33,03-34,10)	31,77±1,39 e (30,88-32,65)
Oxytocin	Before	32,16±1,45 (31,23-33,08)	32,01±1,79 (30,88-33,15)	32,03±1,64 a (30,99-33,07)	30,07±1,58 b (29,07-31,08)
	After	33,30±1,21 (32,54-34,07)	33,50±1,26 (32,70-34,30)	33,27±1,30 (32,44-34,09)	31,86±1,46 b,c (30,93-32,79)
	24hs	32,98±1,47 (32,05-33,91)	33,02±1,48 b (32,08-33,96)	33,40±1,30 a (32,57-34,23)	31,20±1,06 d (30,52-31,87)
	48hs	32,50±2,10 a	32,61±2,05	33,17±1,32	30,14±1,71 c,e

	(31,17-33,84)	(31,31-33,92)	(32,33-34,01)	(29,05-31,22)
p	“a” *p*=0.017#	“a” *p*<0.001* “b” *p*=0.006#	“a” *p*=0.023*	“a” *p*=0.018* “b” *p*=0.004* “c” *p*=0.006* “d” *p*=0.003# “e” *p*=0.005#
F	4.100	7.171* 14.838#	6.536	30.200* 10.815#
ɳ2p	0.272	0.395* 0.574#	0.373	0.733* 0.496#

(ANOVA two way and Post Hoc de Bonferroni). Identical superscript letters indicate statistically significant differences (p ≤ 0.05) (Ex: a-a, b-b), * intraclass (between moments – before, after, 24h and 48h), # interclass (between conditions – oxytocin/placebo); ɳ2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). PE – sternal pectoralis major, PC – clavicular pectoralis major, DA – anterior deltoid, TB – triceps brachii.

In the PE region, an intergroup difference was observed at the 48-hour time point (p = 0.017). In the PC region, an increase was noted between pre-exercise and 24 hours post-exercise (p < 0.001) under the placebo condition, along with an intergroup difference at 24 hours (p = 0.006). In the DA region, an increase was observed between pre-exercise and 24 hours post-exercise (p = 0.023) under the oxytocin condition.

Among the regions analyzed, the TB exhibited the most differences, both within and between groups. Under the placebo condition, an increase was observed between pre-exercise and 24 hours post-exercise (p = 0.018). Under the oxytocin condition, an increase occurred between pre- and post-exercise (p = 0.004), followed by a decrease between post-exercise and 48 hours (p = 0.006). Intergroup differences were noted at 24 hours (p = 0.003) and 48 hours (p = 0.005).

DISCUSSION

The aim of the study was to investigate the effects of intranasal oxytocin on testosterone and cortisol levels, muscular fatigue, and skin temperature following a Paralympic powerlifting training session.

Total Testosterone Behavior

In the placebo condition, an increase of approximately 20% in total testosterone (TT) was observed between post-training and 24 hours, with a high effect size ($ɳ^2p$=0.320). This increase should not be interpreted as an anabolic phenomenon, but rather as a physiological recomposition after the atypical pattern observed immediately after exercise. Thus, the increase observed at 24h appears to reflect a subsequent homeostatic reestablishment of the initial attenuated response, and not an additional hormonal stimulus. We emphasize that in the present study, all hormonal assessments were carried out in the morning and with a short interval between collections, minimizing circadian influence.

Unlike classic findings in able-bodied, resistance-trained individuals, who typically exhibit an acute increase in total testosterone level following strength exercise (Kraemer & Ratamess, 2005), the present sample demonstrated post-exercise reductions in TT under the placebo condition. This unexpected pattern may reflect several population-specific factors, including changes in autonomic function or HPA/HPG axis responsiveness in athletes with physical disabilities, medication use, stress level, chronic pain, circadian influences, and disability-related metabolic and endocrine adaptations. Furthermore, evidence such as that of West et al., 2010 and West & Phillips, 2012, indicates that acute hormonal elevations do not consistently correlate with gains in hypertrophy or strength, suggesting that such responses may be transient mechanisms without a direct impact on chronic muscle anabolism.

Under the oxytocin condition, although no significant changes were observed over time, the response pattern was more stable, without abrupt fluctuations, suggesting a potential protective role of oxytocin in preserving testosterone secretion in response to exercise-induced physical stress. In other words, oxytocin may exert a positive effect on the hypothalamic–pituitary–gonadal (HPG) axis. This stability could be clinically relevant for populations with greater hormonal vulnerability, such as Paralympic athletes, indicating that oxytocin may act as a homeostatic modulator, preventing marked declines in TT. Maintaining total testosterone levels is important, as this hormone is directly associated with anabolic processes, including muscle protein synthesis and the preservation of strength and lean mass (Kraemer & Ratamess, 2005). The fact that the effect size was large in the placebo condition but not under oxytocin reinforces that the intervention did not amplify the rebound effect, but rather may have promoted a more controlled regulation of the androgenic response. Oxytocin has also been shown to modulate stress and reduce HPA axis activation in acute situations (Heinrichs et al., 2003), which could partly explain the preservation of testosterone levels following physical exertion.

Clinically, the preservation of total testosterone following exercise in Paralympic athletes is highly relevant, as these individuals may exhibit baseline hormonal and metabolic alterations due to their neuromuscular conditions (Pereira-

Rosa et al., 2020). Studies indicate that spinal cord injuries and other neuromuscular impairments can affect the HPG axis, resulting in reduced testosterone levels and altered energy metabolism (Bauman et al., 1999; Pereira-Rosa et al., 2020). Therefore, strategies that mitigate the impact of strength training on the hormonal environment are desirable, particularly during periods of high training volume or intensity, when the risk of performance decline or overtraining increases (Meeusen et al., 2013). In this context, oxytocin may represent an ergogenic tool with practical applications in hormonal management for elite athletes with physical disabilities, given its potential to modulate hormonal responses to stress and promote a more favorable anabolic environment (Cardoso et al., 2014).

Therefore, none of the hormonal changes observed here should be interpreted as an anabolic or catabolic mechanism, but only as an acute and transient response. From an interpretative point of view, this behavior reinforces that, even in the absence of oxytocin, the endocrine axis responded in a compensatory manner to acute stress, although such a response should not be extrapolated as indicative of anabolic processes.

Free Testosterone Behavior

Unlike other studies that measured only total testosterone, our study also assessed free testosterone. As testosterone enters the peripheral circulation, it binds to serum proteins such as sex hormone-binding globulin (SHBG – approximately 60%) and albumin (approximately 38%), while roughly 2% remains as “free” testosterone, which represents the fraction available for rapid physiological action (Berne e Levy, 2018). Free testosterone values were obtained using the Vermeulen equation, which utilizes the individually measured values of total testosterone and SHBG, and a fixed albumin value (4.3 g/dL). These values are then plugged into the equation to estimate the free testosterone concentration.

Free testosterone (FT), which represents the biologically active fraction of total testosterone, remained within physiological ranges at all time points and did not show significant changes between conditions ($p = 0.286$). However, a more pronounced reduction was observed in the placebo group post-exercise (from 7.63 ± 2.28 to 6.23 ± 1.87 ng/dL) compared to the oxytocin group (from 7.99 ± 2.89 to 7.12 ± 2.60 ng/dL), indicating a tendency for oxytocin to help maintain FT levels relative to placebo.

Free testosterone (FT) is less influenced by changes in plasma volume than total testosterone, but it still responds to exercise-induced physiological alterations, such as increases in sex hormone-binding globulin (SHBG) and acute shifts in blood pH and body temperature (B. T. Crewther et al., 2009). The observation that FT was better preserved under oxytocin than placebo suggests that oxytocin may mitigate these mechanisms, supporting the maintenance of the biologically active hormonal fraction during the post-exercise physiological stress period and ensuring the availability of active testosterone for anabolic and neuromuscular processes (Hackney & Elliott-Sale, 2021).

From a practical perspective, the maintenance of free testosterone may directly contribute to neuromuscular readiness and short-term recovery, positively influencing the ability to perform subsequent high-intensity training sessions. As the biologically active fraction of testosterone, FT is essential for protein synthesis, muscle strength, and tissue repair (Herbst & Bhasin, 2004); (Kraemer & Ratamess, 2005). In the context of Paralympic powerlifting, where neuromuscular demands are high and recovery may be slower due to pre-existing physiological or functional limitations, oxytocin emerges as a promising neuroendocrine modulator. Although further studies are needed to confirm its long-term effects on FT, preliminary evidence suggests that oxytocin can positively influence the hormonal environment, supporting recovery and athletic performance (Gossen et al., 2012); (Neumann & Landgraf, 2012).

Cortisol Behavior

The hormonal variable that showed the greatest effect magnitude was cortisol. Cortisol findings exhibited a complex pattern: under the placebo condition, levels decreased from pre- to post-exercise (10.07 → 6.72 μg/dL; $p = 0.011$) and from pre-exercise to 24 hours post-exercise (10.07 → 8.08 μg/dL; $p = 0.038$). The effect size was very large ($\eta^2p = 0.573$), indicating a robust magnitude of cortisol reduction. This response aligns with previous studies showing cortisol decreases following high-load strength exercises (≥80%), associated with HPA axis regulation (B. T. Crewther et al., 2011b).

Under the oxytocin condition, cortisol decreased from pre- to post-exercise (9.52 → 6.48 μg/dL; $p = 0.002$), followed by an increase from post-exercise to 24 hours (6.48 → 8.73 μg/dL; $p = 0.039$). The effect size was also very large (η^2p =

0.573), suggesting that oxytocin not only acutely reduced cortisol but also contributed to its recovery within 24 hours, potentially preventing prolonged suppression and attenuating physiological stress. This more dynamic regulation may be linked to central mechanisms of oxytocin in modulating stress and emotional responses to exercise (Neumann & Landgraf, 2012).

Cortisol, the primary hormone of the HPA axis, is highly sensitive to physically stressful stimuli, such as high-load strength training. Acute elevations are expected, however, sustained post-exercise increases may be associated with inhibition of anabolic processes and an increased risk of overtraining (Carrard et al., 2022). Therefore, oxytocin's ability to reduce and maintain lower cortisol levels following exercise suggests a beneficial modulation of the HPA axis, with potential positive effects on recovery and subsequent performance (Takayanagi & Onaka, 2021); (Cardoso et al., 2014).

Thus, the differential temporal effect observed under the oxytocin condition (immediate decrease followed by elevation at 24 hours) aligns with literature describing HPA axis modulation by oxytocin. Intranasal administration of oxytocin has been associated with attenuation of acute cortisol reactivity in human stress tests, although effects depend on context and the magnitude of the challenge (Cardoso et al., 2013; Heinrichs et al., 2003). The 24-hour cortisol increase may reflect a return to the circadian baseline or a homeostatic adjustment following acute suppression. Overall, these findings suggest that oxytocin modulated the temporal dynamics of cortisol, reducing the acute response while allowing subsequent restoration of HPA axis function.

Additionally, it is important to highlight that oxytocin's effects on cortisol may be related to central mechanisms of emotional regulation, reducing the psychological component of exercise-induced stress in addition to peripheral effects, resulting in lower cortisol levels under stressful conditions (Neumann & Landgraf, 2012; Heinrichs et al., 2003). In this context, oxytocin acts not only as a physiological agent but may also influence emotional and motivational aspects of training, promoting better stress adaptation and enhancing performance (Striepens et al., 2011a).

Therefore, the effects of oxytocin on cortisol represent a more robust and mechanistically sustained physiological outcome than the variations observed in testosterone. The literature demonstrates that oxytocin exerts a direct influence on the HPA axis, reducing reactivity to physical and psychological stress and modulating autonomic responses associated with training overload (Cardoso et al., 2014; Neumann & Landgraf, 2012). This perspective is particularly relevant for Paralympic athletes, who frequently face multiple additional sources of stress, such as chronic pain, functional demands, and psychosocial pressures (Pereira-Rosa et al., 2020)., making HPA modulation a physiological target of great interest. Thus, unlike testosterone responses, whose immediate functional value remains controversial and weakly associated with chronic strength adaptations, the cortisol attenuation observed with oxytocin may reflect a more consistent neurophysiological benefit.

Behavior of Dynamic Strength Indicators (45% 1RM)

Regarding mean propulsive velocity (MPV), the data showed that 24 hours after the session, the placebo group exhibited higher values than the oxytocin group (0.80 m/s vs. 0.74 m/s; $p = 0.042$). Despite the statistical difference, both groups experienced a decline relative to baseline, indicating a reduction in propulsive velocity performance. Interestingly, while the oxytocin group demonstrated better MPV recovery at 48 hours (0.92 m/s), the placebo group showed lower recovery (0.83 m/s). These findings suggest that, although oxytocin may induce a slight acute reduction in MPV, it appears to favor neuromuscular recovery in the medium term, consistent with studies linking oxytocin to muscle regeneration and inflammatory modulation mechanisms (Elabd et al., 2014; Gimpl & Fahrenholz, 2001).

The analysis of maximum velocity (VMax) revealed significant effects. In the placebo group, VMax decreased from pre-exercise to 24 hours post-exercise (1.40 m/s → 1.12 m/s; $p = 0.043$), whereas in the oxytocin group the decline was similar (1.39 m/s → 1.06 m/s) but less pronounced. Additionally, a significant intergroup difference was observed post-exercise, favoring oxytocin (1.38 m/s vs. 1.31 m/s; $p = 0.040$), supporting the hypothesis that oxytocin exerts a protective effect on high-velocity performance. The preservation of VMax may be associated with oxytocin's modulation of the HPA axis, reducing stress responses and facilitating motor coordination (MacDonald & Feifel, 2014; Heinrichs et al., 2003).

Regarding muscular power, a significant intergroup difference was observed immediately post-exercise (placebo = 481.82 W vs. oxytocin = 613.73 W; $p = 0.024$; $\eta^2_p = 0.391$), representing a large effect of the oxytocin intervention. Power generation is directly influenced by the interaction between force and velocity, both variables positively modulated by oxytocin at this time, suggesting that oxytocin may enhance mechanical performance during lower-load, high-velocity efforts, particularly when fatigue has not yet developed. This observation aligns with studies indicating central effects of oxytocin on motor excitation and increased motor unit recruitment (Quintana et al., 2015; Zink & Meyer-Lindenberg, 2012).

Dynamic strength variables at 45% of 1RM showed modest differences between conditions and time. Although oxytocin appeared to preserve power and speed immediately after training, these responses also recovered naturally within 48 hours in both conditions. On the other hand, deleterious effects are more observable at 24 hours, the time of greatest neuromuscular depletion. This raises hypotheses about the physiological window of action of oxytocin and its interaction with post-exercise inflammatory and metabolic processes, which demands studies with greater hormonal and biochemical control. The effect size (≥ 0.332) reinforces the practical relevance of the findings.

Despite the promising results, it is important to consider that oxytocin effects may vary according to the athlete’s psychophysiological profile, training level, and individual sensitivity to the peptide. Previous studies have shown that factors such as trauma history, personality traits, and emotional regulation modulate the response to oxytocin (Olff et al., 2013), which may influence its application as an ergogenic aid.

Behavior of Skin Temperature Data

Skin temperature responses assessed by infrared thermography revealed consistent condition-dependent patterns across muscle regions involved in the training protocol. Overall, oxytocin was associated with attenuated or more rapidly normalized post-exercise skin temperature compared to placebo, particularly at 24 and 48h, suggesting a modulation of peripheral responses following intense resistance exercise. Prolonged elevations in superficial temperature are commonly linked to local inflammation, hyperemia, and residual muscle stress; therefore, the lower temperature maintenance observed under oxytocin may reflect a more regulated thermal recovery process rather than sustained inflammatory activity (Fernández-Cuevas et al., 2015, 2017). Although regional variability was evident, especially in muscles more directly loaded by the protocol, such as the pectoral region and triceps brachii, the overall pattern supports the notion that oxytocin influenced vascular and metabolic responses at the peripheral level, consistent with previous evidence linking thermographic changes to physiological stress and muscular overload (Ring & Ammer, 2012).

From a mechanistic perspective, it remains unclear whether the attenuated thermal responses observed under oxytocin primarily reflect reduced exercise-induced fatigue, enhanced post-exercise recovery processes, or a combination of both. Oxytocin may influence these responses through central modulation of stress perception and autonomic activity, including attenuation of HPA axis reactivity (Neumann & Slattery, 2016; Cardoso et al., 2014). In addition, its close functional relationship with vasopressin suggests potential involvement of vascular tone, fluid balance, and osmoregulatory mechanisms, which could secondarily affect muscle temperature and heat dissipation (Verbalis, 2003). Importantly, these findings should not be interpreted as evidence that oxytocin enables athletes to train beyond typical fatigue limits or induces superior training adaptations, but rather as generating testable hypotheses regarding how neuropeptide-mediated modulation of autonomic and peripheral systems may contribute to recovery and resilience following intense resistance exercise.

When analyzed collectively, the data suggest that oxytocin may act as a multifactorial modulator of the training response. This integration of endocrine, neuromuscular, and thermal responses positions oxytocin as a potential ergogenic aid, particularly relevant for Paralympic athletes, who often exhibit increased susceptibility to inflammatory processes and residual fatigue (Fagher & Lexell, 2014).

However, it is important to emphasize that the observed effects are acute and specific to a high-intensity protocol. Future investigations should explore the chronic effects of oxytocin administration at different training loads, as well as its interaction with other psychophysiological variables, to elucidate its true applicability in the context of elite sport.

Although the effects observed in this study are acute and limited to a high-intensity protocol with Paralympic weightlifting athletes, important questions remain for future investigations. In particular, it is still unknown whether repeated administration of oxytocin over weeks or months could lead to the development of tolerance, desensitization of receptors, or a progressive reduction in its physiological effects, phenomena described in other neuropeptidergic systems and which merit systematic investigation. Longitudinal studies comparing athletes who train with and without oxytocin could clarify not only the maintenance of hormonal and autonomic effects, but also whether there is any real impact on competitive performance or resilience to training. Furthermore, it would be relevant to incorporate positive control conditions that stimulate endogenous oxytocin secretion, such as music, therapeutic touch, social bonding, or motivational strategies, allowing for comparison of pharmacological intervention with natural forms of neuropsychophysiological modulation. The use of a triple experimental design, with placebo, oxytocin, and natural oxytocin stimuli, could elucidate mechanisms, distinguish specific effects, and inform more effective and ecologically valid training strategies in elite sports.

The main limitations include modest sample size, exploratory design, lack of psychological measures (e.g., RPE, mood), circadian influences, and limited mechanistic depth.

CONCLUSION

This exploratory study indicates that intranasal oxytocin may attenuate cortisol responses to a high-intensity resistance training session in Paralympic powerlifters, suggesting a modulatory effect on the HPA axis and stress-related physiology. Given oxytocin’s established neurophysiological and autonomic actions, this finding represents the most robust and mechanistically supported outcome of the study, particularly in a population exposed to elevated physical and psychological stressors.

Neuromuscular and thermal responses suggest possible influences on fatigue and recovery; however, these effects were modest and transient, resolving naturally within the recovery period. These results indicate a potential ergogenic effect of oxytocin in supporting recovery and performance. However, longitudinal investigations are needed to confirm its efficacy and safety in competitive contexts.

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

Data Availability Statement: The datasets generated during and/or analysed during the current research are available from the corresponding authors upon reasonable request.

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2.2 – ESTUDO 2 – Evaluation of the use of intranasal oxytocin on indicators of dynamic strength and muscle damage in Paralympic Powerlifting athletes.

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ABSTRACT: Powerlifting training aims to maximize strength and performance, and ergogenic supplementation has been explored to enhance performance and recovery. Oxytocin has emerged as a potential ergogenic aid due to its neuromodulatory and muscle-protective effects. This randomized, double-blind, placebo-controlled trial investigated the effects of intranasal oxytocin on dynamic strength indicators and markers of muscle damage following a high-intensity training session in Paralympic powerlifting athletes. Eleven athletes received a single dose of intranasal oxytocin (24 IU) or placebo prior to testing. After a standardized interval, participants performed a powerlifting protocol at 80% of 1RM. Dynamic strength variables were assessed throughout the session, and blood samples were collected before training, immediately post, and at 24 and 48 h to assess muscle damage markers. At 80% of 1RM, oxytocin resulted in higher maximal velocity (VMax: 0.73 m/s vs. 0.61 m/s; p = 0.030) and power output (564.55 W vs. 457.55 W; p = 0.030) during the fourth set compared to placebo, indicating greater fatigue tolerance. Oxytocin was also associated with lower creatine kinase, lactate dehydrogenase, and aspartate aminotransferase levels at 24 and 48 h post-exercise. These findings suggest that intranasal oxytocin enhances acute performance and attenuates muscle damage, indicating a potential adjuvant ergogenic role in strength training for Paralympic powerlifting athletes.

Keywords: Oxytocin; Dynamic Strength; Muscle Damage; Paralympic Powerlifting; Performance; Fatigue.

INTRODUCTION

Powerlifting is a strength sport characterized by high-intensity training with the primary goal of developing maximal strength (Aidar et al., 2021). Due to its high physical demands and competitive nature, powerlifting has attracted increasing attention from researchers, particularly regarding effective strategies to enhance athletic performance (Hackett et al., 2013), Within this context, Paralympic powerlifting has also gained prominence, distinguished by the bench press as its sole competitive lift (Mendonça et al., 2021).

Thus, a well-structured periodization program, incorporating variations in training volume and intensity as well as specific progression methods, has been shown to directly influence gains in muscle strength and competitive performance (Mesquita Souza et al., 2023). Moreover, neuroendocrine and muscular adaptations induced by resistance training are frequently monitored through physiological markers such as testosterone, cortisol, neuromuscular activation, maximal dynamic strength, and power. These indicators provide valuable insights into both the acute and chronic responses to strength training (Kraemer e Ratamess 2004; Schoenfeld 2010).

Alongside training strategies, nutritional and/or pharmacological supplementation has been widely employed as a resource to potentiate physiological adaptations to resistance training (Menezes, et al., 2023; Mesquita Souza et al., 2023). Substances such as creatine, caffeine, beta-alanine, and even peptide hormones like oxytocin have been investigated for their potential effects on performance and recovery (Kreider et al. 2017; Kerksick et al. 2018). The choice of supplementation to enhance performance and recovery often considers its ability to influence neuromuscular and endocrine systems, which are essential for success in powerlifting (Aidar et al., 2021). In this context, nutritional supplements are widely adopted to improve performance and accelerate recovery following high-intensity efforts (Huerta Ojeda & Jorquera-Aguilera, 2024; Isenmann et al., 2024; Wax et al., 2021).

Among the wide range of supplements, oxytocin—a hormone traditionally associated with affective and social behaviors—has recently emerged as a potential strategy to enhance performance and muscle recovery (Szabó et al., 2024b). This substance has been investigated for its possible effects on exercise-related physiological variables such as strength, power, and fatigue. Evidence suggests that oxytocin may modulate pain perception (Rash et al., 2014), reduce cortisol levels (Cardoso et al., 2014) and positively influence recovery (Cardoso et al., 2013); Lee et al. 2018), thereby representing a novel approach for optimizing resistance training outcomes.

When comparing the combination of strength training (ST) with oxytocin (OT) supplementation to either intervention in isolation, previous evidence has shown greater maximal load when both strategies are applied concurrently. However, these findings were obtained in non-athlete, non-Paralympic populations, and were accompanied by a reduction in total antioxidant capacity, indicating potential limitations related to oxidative stress (Fernandes-Breitenbach et al., 2022). Similarly, studies examining the combination of aerobic and resistance exercise have reported increased plasma OT levels and reduced anxiety; nevertheless, these investigations were also conducted in non-athletic populations and did not assess performance outcomes under high mechanical loads (Wang et al., 2021).

Considering the short half-life of oxytocin, further evidence is required to clarify its acute and residual effects within the context of strength training, particularly during high-intensity exercise. In exercise settings, oxytocin appears to modulate both psychological stress and physiological stress responses; however, circulating OT levels vary according to exercise type, intensity, and duration (Szabó et al., 2024). Moreover, strenuous exercise itself acts as an acute stressor capable of increasing several biomarkers, including oxytocin, especially during the recovery phase (Ryznar et al., 2024).

Importantly, to date, no studies have investigated the effects of oxytocin supplementation on dynamic strength performance under high-load conditions (e.g., 80% of 1RM) in Paralympic athletes, representing a critical gap in the literature. This lack of evidence highlights the need for controlled investigations examining the interaction between oxytocin, high-intensity strength training, and fatigue tolerance in this specific population.

In this context, it becomes relevant to further investigate the physiological effects of oxytocin, with the aim of advancing the understanding of its potential ergogenic and therapeutic roles in high-performance sports (Quintana et al., 2021); (MacDonald & Feifel, 2014). Therefore, the purpose of the present study was to examine the effects of intranasal oxytocin versus placebo on dynamic strength indicators and muscle damage during a training session performed at 80% of one-repetition maximum (1RM).

We hypothesized that oxytocin administration would be likely to enhance performance and attenuate markers of muscle damage in Paralympic powerlifting athletes.

METHODOLOGY

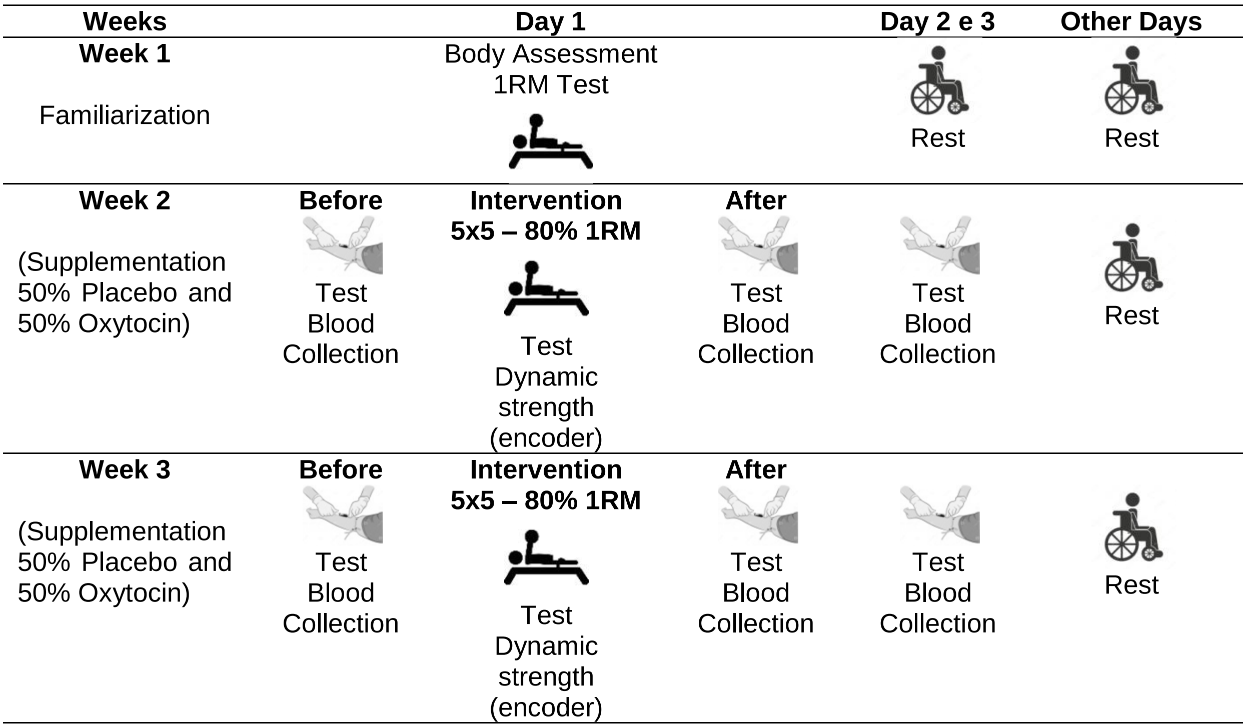
Study design

This study employed a randomized, double-blind, placebo-controlled, within-subject design. Participants received an intranasal administration of either 24 IU (40.32 µg) of oxytocin or placebo (normal saline solution). Experimental sessions were separated by a one-week interval, which was considered sufficient to ensure complete washout, given the short biological half-life of oxytocin and its rapid systemic clearance following intranasal administration. Moreover, this interval was selected to minimize potential carryover effects while accounting for interindividual variability in oxytocin responsiveness, as well as for residual neuromodulatory and physiological effects reported in the literature.

Both oxytocin and placebo were self-administered under supervision, five minutes prior to the onset of testing. To standardize conditions, participants were instructed to fast for at least one hour before each training session and to abstain from caffeine and alcohol consumption on the day of testing (Gorka et al., 2015). Dynamic strength, power, and fatigue gradient tests were initiated five minutes after the intranasal administration of oxytocin or placebo and lasted approximately one hour. This timeframe is consistent with previous administration protocols and aligns with the expected window of oxytocin’s physiological effects (Berends et al., 2021; Gorka et al., 2015).

The study was conducted over a three-week period. During the first week, participants underwent familiarization with the research procedures, including body mass assessment and determination of one-repetition maximum (1RM). In the second week, randomization was performed to allocate participants to either the placebo or oxytocin condition, with a 50% distribution in each group. Following randomization, participants self-administered one intranasal spray per nostril (24 IU/40.32 µg) of synthetic oxytocin or placebo saline solution (both prepared by Pharma Manipulações, Sergipe, Brazil). To maintain blinding, all labeling identifying the contents of the vials was removed prior to the experimental sessions (Gorka et al., 2015).

Immediately following the administration of oxytocin or placebo, pre-training data collection commenced, followed by the training session (5×5: five sets of five repetitions at 80% of each participant’s 1RM). Post-training assessments were conducted immediately after the session, as well as at 24 and 48 hours post-exercise. On the intervening days, participants were instructed to rest. During the third week, a crossover design was implemented: participants who previously performed the session with oxytocin inhalation completed the session with placebo, and vice versa.



Weeks		Day 1		Day 2 e 3	Other Days
Week 1 Familiarization		Body Assessment 1RM Test		Rest	Rest
Week 2 (Supplementation 50% Placebo and 50% Oxytocin)	**Before** Test Blood Collection	**Intervention 5x5 – 80% 1RM** Test Dynamic strength (encoder)	**After** Test Blood Collection	Test Blood Collection	Rest
Week 3 (Supplementation 50% Placebo and 50% Oxytocin)	**Before** Test Blood Collection	**Intervention 5x5 – 80% 1RM** Test Dynamic strength (encoder)	**After** Test Blood Collection	Test Blood Collection	Rest

Figure 1: Experimental Design - Weekly Training Programming

Sample

The sample comprised 14 Paralympic powerlifting athletes with a minimum of 12 months of training experience. All participants were national-level competitors who met the eligibility criteria established by the Brazilian Paralympic Committee (CPB) for participation in the sport (WPPO, s. d.).

However, three participants were excluded from the study, along with their data, for not completing all three weeks of the protocol. Participation was voluntary, and all athletes provided written informed consent in accordance with the ethical principles outlined in the Declaration of Helsinki (1964, amended 1975, 1983, 1989, 1996, 2000, 2008, and 2013) of the World Medical Association.

This study was approved by the local ethics committee under protocol number 2.637.882. Sample characterization data are presented in Table 1.

Table 1: Characterization of subjects

	(Mean±SD)
Age (years)	33,90±10,67
Body Weight (kg)	77,22±21,22
Experience (years)	4,40±1,78
1RM Bench Press Test (kg)	141,50±35,44*
1RM/Body Weight	1,91±0,52**

* All athletes with loads that keep them among the top 10 in their categories at the national level.
** Values above 1,4 in the Bench Press would be considered elite athletes (Ball & Weidman, 2018).

Instruments and Procedures

Athletes' body mass was measured using a Michetti digital platform scale (Brazil) with a maximum capacity of 300 kg and dimensions of 1.50 × 1.50 m, allowing for seated weighing.

Data on mean propulsive velocity (MPV, m/s), maximal velocity (Vmax, m/s), and power output (W) were collected using a linear position transducer (encoder) from Vitruve (Madrid, Spain) (Pérez-Castilla et al., 2019). Strength data were evaluated with a load of 80% of 1RM, where 5 repetitions were performed in each series.

A trained healthcare professional (laboratory technician) collected 10 mL of blood from the antecubital vein of the forearm using vacuum tubes containing a clot activator gel. Blood samples were allowed to rest at room temperature for 30 minutes, followed by centrifugation for 10 minutes to separate the serum. The serum was then stored and sent to the Clisa Laboratory (Aracaju, Sergipe, Brazil), where analyses were performed by a laboratory biochemist. Muscle damage markers were assessed using the Enzymatic Method.

Load Determination

During the familiarization week, the one-repetition maximum (1RM) test was performed. Each participant began with a load they believed could be lifted only once using maximal effort. Incremental loads were then added until the maximum weight that could be lifted once was determined. If the participant was unable to complete a single repetition, 2.4–2.5% of the load used in the previous attempt was subtracted (J & William, 2014). Participants rested for 3–5 minutes between attempts. All participants completed the 1RM test both before and after the training session, with a minimum interval of 10 minutes between the tests and the training session.

Warm-up

Prior to the intervention, athletes performed an upper-body warm-up consisting of three exercises: shoulder abduction with dumbbells, elbow extension on a pulley, and shoulder rotation with dumbbells. Each exercise was performed for three sets of 10–20 repetitions at an approximate intensity corresponding to 10–20RM, over a duration of about 10 minutes (Austin & Mann, 2020).This was followed by a specific warm-up on the flat bench press at 30% of 1RM, consisting of 10 slow repetitions (3.0 × 1.0 seconds, eccentric × concentric) and 10 fast repetitions (1.0 × 1.0 seconds, eccentric × concentric). Immediately afterward, the experimental intervention commenced.

Statistical Analysis

Central tendency measures, including the mean and standard deviation (X ± SD), as well as the 95% confidence interval (CI 95%), were utilized. Given the sample size, the Shapiro–Wilk test was conducted to verify the normality of the data. A two-way ANOVA (condition x moment) for repeated measures, followed by Bonferroni post hoc tests, was employed.The effect size was assessed using the partial eta squared (η^2_p), with magnitudes classified as low < 0.05, medium 0.05 to <0.25, high 0.25 to <0.50 and very high ≥0.50. (Cohen, 1992). Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS), version 24. A significance level of $p < 0.05$ was adopted for all analyses (IBM, New York, NY, USA).

RESULTS

Figure 2 presents the dynamic strength results, assessed through mean propulsive velocity (MPV), maximal velocity (Vmax), and muscle power at 80% of 1RM, measured at pre-training, post-training, 24 h, and 48 h time points, for both inter- and intra-group comparisons.

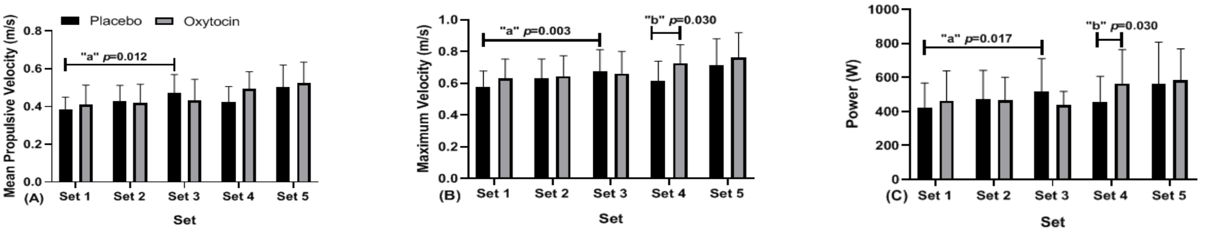


Figure 2: Dynamic Indicators of Strength, (A) Mean Propulsive Velocity (m/s), (B) Maximum Velocity (m/s) and (C) Power (W), with 80% 1RM (Mean ±SD; 95% CI) in 5 training sets with the use of a placebo and oxytocin in Paralympic Powerlifting.

At the 80% 1RM load, mean propulsive velocity (MPV) showed a significant difference only within the placebo condition between sets 1 and 3 (*p* = 0.012). Maximum velocity (VMax) presented both intraclass differences in the placebo condition between sets 1 and 3 (*p* = 0.003) and interclass differences in set 4 (*p* = 0.030). Similarly, power demonstrated differences along the same timeline as VMax, with intraclass differences in the placebo condition between sets 1 and 3 (*p* = 0.017) and interclass differences in set 4 (*p* = 0.030).

Table 2 presents the muscle damage results, assessed via enzymatic markers (Creatine Kinase – CK, Lactate Dehydrogenase – LDH, Alanine Aminotransferase – ALT, and Aspartate Aminotransferase – AST) at pre-training, post-training, 24 h, and 48 h time points.

Table 2: Muscle damage (Mean ± SD; 95% CI) at different time points during traditional training and following oxytocin/placebo administration in Paralympic powerlifting.

Condition	Time point	CK U/L	LDH U/L	ALT U/L	AST U/L
Placebo	Before	274,18±161,41 a (165,75-382,62)	367,27±66,58 (322,54-412,00)	46,18±35,16 (22,56-69,81)	30,55±10,83 (23,27-37,82)
	After	310,36±176,18 a (192,00-428,72)	396,36±75,48 (345,66-447,07)	45,55±33,31 (23,17-67,92)	30,91±9,03 (24,84-36,97)
	24hs	418,55±290,39 (223,46-613,63)	409,64±86,52 c (351,51-467,76)	46,45±35,01 (22,94-69,97)	32,73±11,13 a (25,25-40,20)
	48hs	324,27±243,41 (160,75-487,80)	393,82±72,54 d (345,08-442,55)	46,27±34,62 (23,02-69,53)	33,36±11,38 (25,72-41,01)
oxytocin	Before	275,55±190,59 b (147,50-403,59)	374,73±61,06 a (333,71-415,75)	45,27±26,33 (27,59-62,96)	34,73±8,90 (28,75-40,71)
	After	356,64±217,02 c (210,84-502,43)	365,36±56,79 b (327,21-403,52)	43,00±22,98 (27,56-58,44)	34,55±6,99 (29,85-39,24)
	24hs	393,27±223,12 b,c,d (243,38-543,17)	356,64±67,14 c (311,53-401,74)	43,55±23,25 (27,93-59,16)	33,91±8,56 a (28,16-39,66)
	48hs	332,00±193,66 d (201,90-462,10)	328,55±60,58 a,b,d (287,85-369,24)	43,64±23,38 (27,93-59,34)	33,36±8,61 (27,58-39,14)
	P	“a” *p*=0.046* “b” *p*=0.019* “c” *p*=0.011* “d” *p*=0.016*	“a” *p*=0.005* “b” *p*=0.003* “c” *p*=0.005# “d” *p*=0.001#	0.408	“a” *p*=0.025#
	F	6.342	12.150* 6.216#	XXX	3.187

ɳ2p	0.388	0.549* 0.383#	XXX	0.242

(ANOVA two way and Post Hoc de Bonferroni). Identical superscript letters indicate statistically significant differences ($p \leq 0.05$) (Ex: a-a, b-b), * intraclass (between moments – before, after, 24h and 48h), # interclass (between conditions – oxytocin/placebo); η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050).

Regarding the variables indicative of muscle damage, differences were observed both across time points and between conditions (oxytocin/placebo). For creatine kinase (CK), there was an increase between pre- and post-exercise in the placebo condition ($p = 0.046$), as well as between post- and 24 h in the oxytocin condition ($p = 0.019$; $p = 0.011$). A decrease was also observed between 24 h and 48 h in the oxytocin condition ($p = 0.016$). For lactate dehydrogenase (LDH), significant differences were found both intraclass, within the oxytocin condition (pre vs. 48 h, $p = 0.005$; post vs. 48 h, $p = 0.003$), and interclass (24 h, $p = 0.005$; 48 h, $p = 0.001$). No differences were observed for alanine aminotransferase (ALT), whereas aspartate aminotransferase (AST) presented an interclass difference at 24 h ($p = 0.025$).

DISCUSSION

The aim of this study was to investigate the effects of intranasal oxytocin versus placebo on dynamic strength indicators and muscle damage during a single training session at 80% of 1RM in Paralympic Powerlifting.

Dynamic Strength Indicators

In the high-intensity protocol (80% of 1RM), data analysis revealed positive effects of oxytocin, particularly during the final stages of the training session, with a notable impact on performance and resistance to fatigue, especially when compared to the placebo condition.

Analysis of mean propulsive velocity (MPV) showed that the placebo group exhibited a progressive increase up to set 3, indicating progressive neuromuscular warm-up. However, this trend reversed in the subsequent sets (S4 = 0.42 m/s), suggesting the accumulation of fatigue. In contrast, the oxytocin group maintained MPV during the initial sets (S1 to S3), with a marked increase observed only in set 4 (S4 = 0.49 m/s) and set 5 (S5 = 0.52 m/s). Although between-group differences did not reach statistical significance for this variable, the progression observed in the oxytocin group suggests greater efficiency in fatigue management and better preservation of velocity in the later stages of the effort, which may be associated with oxytocin's central neuromodulatory effects, potentially influencing perceptual and psychophysiological responses to exercise-related stress, as suggested by evidence from human studies (MacDonald et al. 2013; Heinrichs et al. 2003).

For maximal velocity (Vmax), within-group differences were observed for the placebo condition (S1 → S3), and a between-group difference emerged in set 4, with an advantage of approximately 15% for the oxytocin group (0.73 m/s vs. 0.61 m/s; p = 0.030). These findings support the notion that oxytocin may positively influence maximal execution velocity under physiological stress, potentially by attenuating stress responses and enhancing neuromuscular efficiency, as suggested by Cardoso et al. 2013 and Quintana et al. (2015). The maintenance of Vmax even after multiple high-intensity sets indicates a potential role of oxytocin in preserving explosive performance under heavy load conditions.

Regarding muscle power, which depends on the interaction between force and velocity, within-group differences were observed in the placebo group (S1 → S3), followed by a subsequent decrease in the later sets (S4 = 457.55 W). In contrast, the oxytocin group displayed more consistent values throughout the protocol and surpassed the placebo in set 4 (564.55 W vs. 457.55 W; $p = 0.030$), maintaining performance through set 5 (585.45 W). These findings suggest an acute ergogenic effect of oxytocin, promoting higher power output during periods of elevated demand. Oxytocin's potential role in reducing perceived exertion (RPE) and enhancing synaptic efficiency and motor unit recruitment may explain these performance improvements (Zink e Meyer-Lindenberg 2012; Lopes and Osório 2023).

The effects observed in the present study are consistent with literature indicating oxytocin as a relevant neuromodulator in the context of physical exercise. Its well-documented anxiolytic effects (Heinrichs et al., 2003), may facilitate the regulation of the hypothalamic–pituitary–adrenal (HPA) axis and contribute to a more efficient response to exercise-induced stress. Furthermore, evidence suggests that oxytocin can positively influence motivation, social cohesion, and persistence in complex motor tasks—factors that are crucial in strength sports (MacDonald e Feifel 2014 ; Striepens et al. 2011).

Analysis of the effect size further highlights the practical relevance of these findings. Large and very large effects ($\eta^2_p \geq 0.390$) were observed for the most impacted variables, such as Vmax and power, both within and between groups, indicating that the effects of oxytocin are not only statistically significant, but also functionally and sport-wise relevant.

However, it should be considered that the effects of oxytocin may be modulated by individual factors, such as the athlete’s neuroendocrine profile, training history, and emotional state (Quintana et al., 2015). Moreover, the isolated use of acute doses may be limited in terms of effect duration, highlighting the need for studies exploring chronic administration protocols or combining oxytocin with structured training periodization strategies.

In summary, the findings of the present study indicate that acute administration of oxytocin may enhance the production and maintenance of strength under high-intensity conditions, with a particular impact on maximal velocity and muscle power during critical phases of training. These effects may have significant implications for training and recovery planning in strength sports, such as Paralympic Powerlifting.

Muscle Damage

Markers of muscle damage (Fraga et al., 2020), such as creatine kinase (CK), lactate dehydrogenase (LDH), alanine aminotransferase (ALT), and aspartate aminotransferase (AST), provide sensitive information regarding muscle integrity and exercise-induced physiological stress. All of these enzymes play key roles in cellular metabolism, and elevated blood levels may serve as indicators of muscle injury or damage (Aidar et al., 2025). In the present study, the effects of acute intranasal oxytocin administration were evaluated against placebo in a population of Paralympic athletes subjected to high-intensity training sessions (80% of 1RM), aiming to understand potential protective actions of oxytocin against muscle damage.

CK is widely used as an indirect marker of structural muscle damage, particularly following eccentric contractions and high-intensity efforts (Brancaccio et al., 2007). The results show that, after training, CK increased in both groups, with peaks observed at 24 h (placebo: 418.55 ± 290.39 U/L; oxytocin: 393.27 ± 223.12 U/L), followed by reductions at 48 h (placebo: 324.27 ± 243.41 U/L; oxytocin: 332.00 ± 193.66 U/L). Between-group analysis indicates that, although CK increased in both conditions, the oxytocin group exhibited lower absolute means and reduced variability at critical time points (24 h and 48 h). The time differences ($p = 0.046$ a; $p = 0.019$ b; $p = 0.011$ c; $p = 0.016$ d) and the large effect size ($\eta^2_p = 0.388$) suggest that oxytocin may have partially attenuated muscle damage induced by high-intensity training.

These findings are consistent with experimental studies demonstrating that oxytocin possesses regenerative and anti-inflammatory properties. For example, (Elabd et al., 2014), showed that oxytocin promotes muscle regeneration in animal models by accelerating satellite cell activation and restoring tissue architecture. Furthermore, oxytocin may modulate the stress response and reduce catecholamine release, thereby attenuating the intensity of the exercise-induced inflammatory response (Cardoso et al., 2014).

Lactate Dehydrogenase is a marker associated with muscle cell membrane disruption and anaerobic metabolism (Totsuka et al., 2002). The present study showed an intraclass decrease in LDH within the oxytocin group, between pre- and 48 h ($p = 0.005$) and between post- and 48 h ($p = 0.003$). Interclass comparisons revealed differences in favor of oxytocin ($p < 0.005$; $\eta^2p = 0.383$), suggesting a potential protective effect of oxytocin on skeletal muscle cell membrane integrity.

Human studies have shown that oxytocin can reduce sympathetic activity and modulate the inflammatory response through interaction with specific receptors present in immune and muscle cells (Szeto et al., 2013). Therefore, the attenuation of LDH may reflect reduced cell lysis and a lower structural impact from training, potentially mediated by oxytocin.

Although ALT and AST are traditionally associated with hepatic metabolism, their elevations can also indicate muscle damage, as they are released from non-hepatic tissues, including skeletal muscle, particularly following strenuous exercise (Pettersson et al., 2008). In the present study, no significant differences were observed for ALT between groups or across time points ($p = 0.408$), indicating that this enzyme was not sufficiently sensitive to detect changes within the context of the present protocol. Conversely, AST showed a between-group difference at 24 h ($p = 0.025$; $\eta^2_p = 0.242$), with lower values in the placebo group (32.73 ± 11.13 U/L) compared to the oxytocin group (33.91 ± 8.56 U/L). Although the difference appears modest, the response pattern suggests a more efficient modulation of systemic muscle damage with oxytocin administration.

The presence of oxytocin receptors in muscle and liver tissue may explain these effects, as oxytocin is capable of acting not only on the central nervous system but also on peripheral musculature and local inflammatory processes (Gimpl & Fahrenholz, 2001).

The integrated analysis of dynamic strength data and muscle damage markers suggests that acute oxytocin administration may have favored the preservation of muscular performance alongside attenuation of exercise-induced physiological stress. The improvements observed in power and maximal velocity at 80% of 1RM in the oxytocin group temporally coincided with lower CK and LDH levels at 24 h and 48 h post-training compared to placebo. These findings support the hypothesis that oxytocin may exert myoprotective effects, reducing microdamage induced by high-intensity training, which in turn contributes to the maintenance of neuromuscular performance. Plausible physiological mechanisms include the modulation of local and systemic inflammation through oxytocin binding to its receptors in myocytes and immune cells, which may attenuate neutrophil recruitment and the release of pro-inflammatory cytokines (Elabd et al., 2014; Szeto et al., 2013). Additionally, evidence suggests that oxytocin can influence motor unit activation efficiency, promoting improved intermuscular coordination even under metabolic stress conditions (Gimpl & Fahrenholz, 2001; Quintana et al., 2015). The association between reduced muscle damage and enhanced explosive performance highlights a potential ergogenic window for oxytocin, particularly in athletes with disabilities, who face elevated physiological and psychosocial demands during competitive training.

Study Limitations

This study presents some limitations, including the sample size, which, although it was a within-subjects design, was small and likely reduced the statistical power. Additionally, our sample was specific to high-performance athletes, limiting the generalizability of the findings to other populations with physical disabilities, and even less so to athletes from different high-performance sports. Chronic studies are needed to better understand the effects of oxytocin on sports performance, particularly in disciplines where maximal strength is a key determinant of competitive success.

CONCLUSION

The findings of this study indicate that intranasal oxytocin was associated with set-specific improvements in dynamic strength variables, particularly power output and maximal velocity during the later stage of a high-load (80% 1RM) training session, in Paralympic powerlifting athletes. Additionally, oxytocin was associated with lower post-exercise levels of muscle damage markers, suggesting a potential modulatory effect on exercise-induced muscle stress. These effects were not generalized across the entire training session and should be interpreted as exploratory.

Collectively, the results suggest that oxytocin may exert acute, context-dependent influences on performance and recovery-related outcomes under high mechanical load. However, its role as an ergogenic aid remains preliminary, and ethical considerations, including regulatory and antidoping implications, must be carefully addressed before any practical application.

Future studies should investigate chronic administration protocols, clarify direct neurophysiological and muscular mechanisms, and better characterize oxytocin pharmacokinetics in athletic populations, particularly in Paralympic sport contexts that demand high technical proficiency and rapid recovery.

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3 – CONSIDERAÇÕES FINAIS

Embora os dados do presente estudo indiquem efeitos benéficos da ocitocina sobre o desempenho muscular e o dano tecidual em curto prazo, é importante destacar alguns potenciais pontos negativos e limitações fisiológicas associados ao seu uso como suplemento no esporte, sobretudo considerando seu papel como neuromodulador sistêmico, e não apenas como um agente periférico.

1. Possível interferência no equilíbrio anabólico-catabólico – a ocitocina está envolvida na modulação do eixo hipotálamo-hipófise-adrenal (HPA), promovendo geralmente uma redução da liberação de cortisol (Cardoso et al., 2014; Neumann & Landgraf, 2012). Embora isso possa parecer vantajoso ao reduzir a resposta catabólica ao estresse físico, existe o risco de inibir mecanismos adaptativos essenciais, uma vez que níveis fisiológicos de cortisol após o exercício são necessários para ativar genes relacionados à regeneração, ao metabolismo energético e à hipertrofia (Hackney, 2006). A supressão crônica da resposta hormonal ao estresse pode, paradoxalmente, comprometer o estímulo adaptativo ao treinamento, especialmente em atletas de alto rendimento que dependem de ciclos bem regulados de estresse e recuperação.

2. Potencial efeito de dessensibilização dos receptores – a exposição repetida à ocitocina pode levar à dessensibilização de seus receptores (OXTR), como observado em estudos com administrações prolongadas (Gimpl & Fahrenholz, 2001; (Leng & Ludwig, 2016). Essa dessensibilização pode reduzir a efetividade da ocitocina ao longo do tempo, alterando seu papel na modulação do comportamento motor, na analgesia e nos processos regenerativos. No contexto esportivo, isso pode gerar perda de efeito ergogênico, além de impactar negativamente processos psicossociais mediados por ocitocina, como motivação, confiança e empatia, que são aspectos importantes em ambientes competitivos e de equipe (Zink & Meyer-Lindenberg, 2012).

3. Risco de uso não regulamentado e implicações éticas – atualmente, a ocitocina não consta na lista de substâncias proibidas pela WADA (Agência Mundial Antidoping), mas seu uso como suplemento ergogênico ainda não é regulamentado, o que pode abrir precedentes para o uso abusivo ou não supervisionado no esporte. A suplementação de hormônios endógenos pode levantar questionamentos éticos

sobre o fair play, especialmente se os efeitos sobre o desempenho forem comprovadamente relevantes, como sugerem os dados de preservação da força e redução de dano muscular neste estudo.

4. Efeitos colaterais cardiovasculares e autonômicos – a ocitocina têm ação direta sobre o sistema cardiovascular, podendo causar vasodilatação, hipotensão e bradicardia reflexa, sobretudo em indivíduos sensíveis ou em condições de sobrecarga fisiológica (Gutkowska et al., 2014). Ainda que os efeitos adversos sejam mais comuns com doses farmacológicas ou administração intravenosa, o uso repetido de ocitocina intranasal pode alterar a regulação autonômica, o que poderia representar um risco em esportes de alta exigência cardiovascular como o *Powerlifting* Paralímpico, onde há tendência ao aumento agudo da pressão arterial e da frequência cardíaca durante os levantamentos máximos (MacDougall et al., 1985).

Conclusão crítica – Portanto, embora a ocitocina mostre potencial ergogênico promissor, seu uso no esporte deve ser abordado com cautela científica e ética. São necessárias mais investigações que explorem o uso crônico, os efeitos dose-dependentes, a variabilidade interindividual e os possíveis riscos de desregulação hormonal e autonômica. A adoção de estratégias baseadas em evidência e com respaldo clínico é fundamental para garantir segurança, eficácia e legalidade no contexto do esporte de alto rendimento.

4 – CONCLUSÕES GERAIS

Com base nos objetivos dos dois estudos experimentais e nos resultados encontrados, conclui-se que a ocitocina foi capaz de modular positivamente o eixo endócrino, promovendo a redução dos níveis de cortisol, o que reflete um ambiente hormonal mais favorável à recuperação e ao desempenho. Além disso, observou-se maior estabilidade térmica nas regiões musculares solicitadas no movimento de supino adaptado, sugerindo menor inflamação local e menor estresse periférico, o que indica potencial de atenuação da fadiga por mecanismos autonômicos e inflamatórios.

Do ponto de vista funcional, os indicadores dinâmicos de força, velocidade média propulsiva, velocidade máxima e potência, foram melhor preservados nos momentos de maior depleção neuromuscular, especialmente após o exercício com cargas elevadas (80% de 1RM), o que aponta para um possível efeito neuromodulador da ocitocina sobre a fadiga central e periférica. Esses efeitos também se refletiram nos marcadores bioquímicos de dano muscular, uma vez que as concentrações de CK, LDH e AST foram significativamente menores após o uso da ocitocina, principalmente nas 24h e 48h pós-treino. A correlação entre desempenho, hormônios, temperatura cutânea e enzimas musculares sugere que a ocitocina atua de maneira sistêmica e integrada, oferecendo proteção fisiológica ao atleta durante e após o estresse induzido pelo treino.

Sendo assim, diante dos achados, conclui-se que a ocitocina intranasal representa uma intervenção ergogênica emergente, com efeitos relevantes sobre variáveis hormonais, térmicas, neuromusculares e bioquímicas. Sua aplicabilidade prática pode ser especialmente valiosa em populações com maior susceptibilidade ao acúmulo de fadiga e dano muscular, como os atletas paralímpicos. No entanto, apesar dos resultados promissores, a utilização da ocitocina como recurso de apoio no treinamento de força ainda requer investigação mais aprofundada quanto à segurança, dosagem, resposta individual e efeitos em longo prazo, para que sua inserção no contexto esportivo ocorra de maneira ética, eficaz e embasada em evidências sólidas.