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Modulation of handgrip strength by contralateral hip flexor motor overflow: randomized controlled trial

Modulação da força de preensão palmar por overflow motor de flexor de quadril contralateral: ensaio clínico controlado e randomizado

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ABSTRACT

Objective: To assess whether the motor overflow generated by the contralateral isometric contraction of the hip flexors attenuates the drop in handgrip strength (HGS) in a repetitive maximal strength protocol in healthy adults. **Method:** Ninety participants were randomized into control and overflow groups. Handgrip strength was measured in the baseline and test phases using a hand dynamometer. In the test phase, the overflow group performed maximal isometric contractions of the hip flexors simultaneously with the HGS tasks (6 seconds, 9 seconds rest). Multivariate analysis of variance (MANOVA) assessed differences by group, gender, hand and phase. **Results:** The control group showed a significant reduction in HGS between phases (p<0.05), while the overflow group maintained HGS in the test phase (p>0.05). Effect sizes (Cohen's d=0.71-0.87) indicated medium to high clinical relevance, suggesting neural facilitation by contralateral activation. **Conclusion:** Motor overflow of the hip flexors supports HGS in repetitive tasks, with potential application in neuromuscular rehabilitation. Strategies based on motor overflow can optimize strength and reduce fatigue in therapeutic protocols.

Keywords: Hand Strength, Isometric Contraction, Hip, Rehabilitation

RESUMO

Objetivo: Avaliar se o overflow motor gerado pela contração isométrica contralateral dos flexores do quadril atenua a queda da força de preensão palmar (FPP) em protocolo de força máxima repetitiva em adultos saudáveis. **Método**: Noventa participantes foram randomizados em grupos controle e *overflow*. A FPP foi mensurada em fases basal e de teste com dinamômetro manual. Na fase de teste, o grupo *overflow* realizou contrações isométricas máximas dos flexores do quadril simultaneamente às tarefas de FPP (6 segundos, 9 segundos de descanso). Análise de variância multivariada (MANOVA) avaliou diferenças por grupo, sexo, mão e fase. **Resultados**: O grupo controle apresentou redução significativa da FPP entre as fases (p<0,05), enquanto o grupo *overflow* manteve a FPP na fase de teste (p>0,05). Tamanhos de efeito (Cohen's d=0,71-0,87) indicaram relevância clínica média a alta, sugerindo facilitação neural pela ativação contralateral. **Conclusão**: O overflow motor dos flexores do quadril sustenta a FPP em tarefas repetitivas, com potencial aplicação em reabilitação neuromuscular. Estratégias baseadas em overflow motor podem otimizar força e reduzir fadiga em protocolos terapêuticos.

Palavras-chaves: Força da Mão, Contração Isométrica, Quadril, Reabilitação

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Conflict of Interests
Nothing to declare

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INTRODUCTION

Maintaining muscle strength during repetitive tasks represents a significant challenge in the physical rehabilitation of various populations, with or without neurofunctional disorders.[1] This obstacle manifests most notably in clinical contexts, where processes associated with fatigue or motor deficits impede training, necessitating techniques that maximize motor recruitment to enhance strength and functional capacity.[2] Proprioceptive neuromuscular facilitation (PNF), a technique developed by Kabat and Knott in the 1940s,[3] utilizes the activation of strong muscles to enhance the contraction of weaker muscles through diagonal movement patterns.[4] These patterns have been shown to trigger muscle force irradiation, a neuromuscular facilitation process that combines biomechanical and neural responses to improve functional movements.[5] For instance, the activation of large muscle groups, such as the hip, knee, and ankle flexors (triple flexion), has been shown to intensify coordination and strength in contralateral muscles of the upper limb, thereby promoting wrist and finger flexion.[6,7] While this inter-limb facilitation holds great promise, its practical implementation is often constrained by the intense muscle activation and exertion demanded, which is further limited by the therapist's expertise or the patient's physical limitations, such as reduced endurance or difficulty in comprehending movement execution instructions.[8,9]

These limitations underscore the necessity to investigate the mechanisms of irradiation, a subject that remains a subject of debate in the literature.[10] Research indicates that this phenomenon may result from biomechanical chains, which involve the propagation of force through the robust activation of large muscle groups, or from neural facilitation, where motor overflow amplifies the activation of muscles not directly involved.[9,10] Motor overflow, defined as the involuntary activation of muscles beyond their primary function, is evoked in contractions exceeding 70% of maximum voluntary isometric contraction (MVIC).[11,12] The isolation of a specific movement, such as the hip flexor, facilitates a systematic examination of these contributions, thereby providing a comprehensive understanding of whether biomechanical or neural pathways predominate in irradiation.[8,13] In contrast to the conventional synergistic and multi-joint patterns characteristic of PNF, which are aimed at enhancing coordination and strength,[3,14] this unconnected approach presents a novel experimental perspective. By focusing on a specific movement, the contralateral effects of irradiation on non-homologous muscles, such as handgrip strength (HGS), can be assessed. This corroborates evidence that motor overflow extends beyond homologous pairs,[13,15] with the potential to improve functional outcomes in rehabilitation.[1,16,17]

According to the extant literature, intense unilateral contractions have been demonstrated to elevate motor cortex excitability, with the potential to amplify force in muscles controlled by the same cortical hemisphere.[12,14] In light of the observations pertaining to overflow in peripheral neuropathies,[12] a hypothesis was formulated positing that the contralateral MVIC of the hip flexors might induce a modification in the maintenance of HGS generation during repetitive and strenuous tasks, which necessitate substantial motor stimulation, thereby demonstrating neural facilitation between non-homologous muscles. Contrary to studies that have focused on homologous pairs,[13] this research makes an original contribution by elucidating how the isolated activation of a movement that generates significant force can modulate force generation during an exhausting task, possibly by modulating cortical excitability in the context of FNP,[14] thereby advancing knowledge about the neural mechanisms of irradiation.

OBJECTIVE

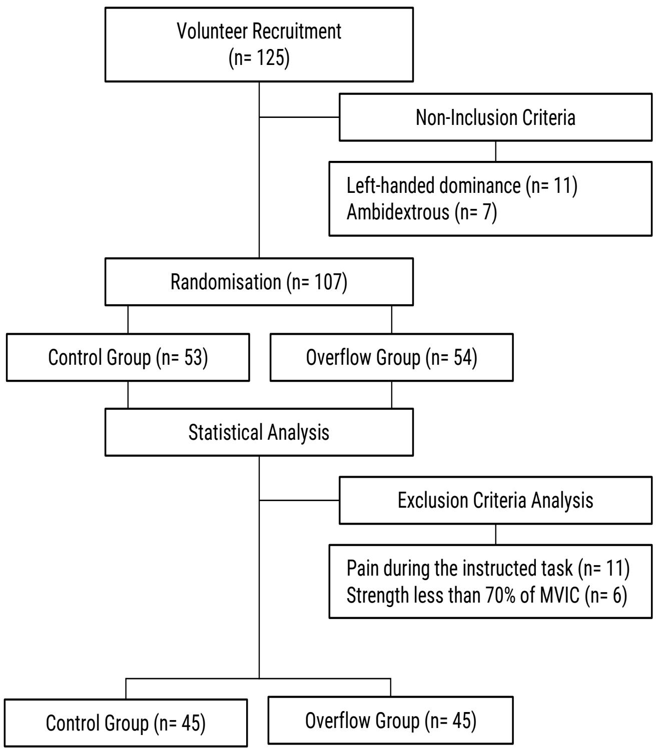
The present study investigates motor overflow between the hip flexors and HGS in healthy adults, using isolated hip flexor activation as an experimental model to explore the processes linked to irradiation.

METHOD

The researchers recruited participants by posting information at the Ribeirão Preto Medical School - University of São Paulo, Brazil. The posters included study details, where the research would take place, instructions for participation, and the researchers' contact telephone numbers. One hundred twenty-five healthy adults between 18 and 30 years old were contacted for this study.

The inclusion criteria necessitated dexterity, which was assessed by the Edinburgh Handedness Inventory (EHI) validated for Brazilian Portuguese,[17] with the objective of ensuring behavioral homogeneity.[18,19] Exclusion criteria encompassed neurological or orthopedic conditions affecting the upper or lower limbs, recent surgical interventions, or an inability to perform maximal contractions due to pain or comprehension difficulties, as assessed through pre-screening interviews.

The sample size was calculated for two groups with a 95% confidence level (Z= 1.96), a sampling error of 3 kilograms, and an estimated standard deviation of 10 kilograms. This calculation resulted in a minimum of 45 participants per group. The randomization process for the control and overflow groups was executed using Random.org software. Simple randomization ensured balanced allocation to the control and overflow groups, minimizing selection bias and maintaining group comparability (Figure 1).



n= Number of subjects; MVIC= Maximum Voluntary Isometric Contraction

Figure 1. Analysis Flowchart

Experimental Procedures

The tests were conducted in a single session at the Neuropsychobiology and Motor Behavior Laboratory at FMRP-USP. HGS was measured using a DIGI-II-SH5003 digital hand dynamometer (Saehan, Masan, Korea), following the guidelines of the American Society of Hand Therapists (ASHT).[20] The subject was required to adduct the arm, position the elbow at 90°, and keep the forearm neutral while ensuring the contralateral arm was relaxed against the chest. The protocol for the control and overflow group (Figures 2A and 2B) included two phases:

Baseline phase: Both groups performed three maximal voluntary isometric contractions (MIVC) of HGS (6 seconds each, 9 seconds of rest) in each hand, with a 1-minute interval between hands. The maximum value of the first trial (LB1, in Newtons) was defined as 100%, with subsequent trials (LB2 and LB3) expressed as percentages of LB1.

Test phase: During the test phase, both groups performed three Hand Grip Strength (HGS) trials (T1, T2, T3; 6 seconds each, followed by 9 seconds of rest). The maximum value of the first trial (T1, in Newtons) was established as 100% for both groups, with T2 and T3 expressed as percentages of T1. The control group repeated the baseline protocol without additional activation, while the overflow group performed HGS concurrently with MVIC of the contralateral hip flexor (e.g., right hip to left hand). Hip flexion was measured in a seated position, with a backrest, without trunk straps, using a Dyna Mop dynamometer (Fitpulley, Santos, Brazil).

The dynamometer was fixed to the distal thigh by a rigid strap and anchored to the floor by a chain, limiting the movement to 30°. The contralateral leg remained fixed to the floor (Figure 2C).

Following a 10-minute rest period, the overflow group underwent an isolated strength assessment (ISSA) of hip flexion (6 seconds each, 9 seconds of rest) with three MVIC. It was determined that participants with MVIC scores below 70% would be excluded from further analysis. The maximum value of the initial trial (T1, in Newtons) was established as 100%, with subsequent trials (T2 and T3) denoting percentages relative to T1.

All measurements were overseen by trained researchers, with the exclusion of participants experiencing pain or postural compensation (e.g., trunk tilt) to mitigate biomechanical interference.

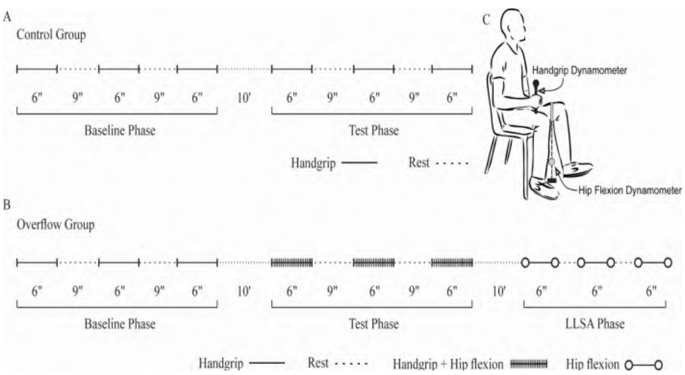


Figure 2. Experimental design for the control group (A), the overflow group (B) and the positioning of the handgrip dynamometer to assess right HGS strength and the floor-standing hip flexion dynamometer to assess left hip flexion strength (C)

Outcome Measures

The primary outcome, HGS, was standardized as a percentage of the first trial (LB1 in the baseline phase and T1 in the test phase) to adjust for inter-individual variability. The MVIC of the hip flexor, a secondary measure, confirmed the threshold for inducing overflow (≥70% of the MVIC), associated with corticospinal facilitation.[14]

Statistical Analysis

Data were analyzed using SPSS (v.26). Independent t-tests compared anthropometric characteristics (age, weight, height) and baseline handgrip strength (HGS) between control and overflow groups, while chi-square tests assessed gender homogeneity. HGS was expressed as a percentage of LB1 (baseline phase) and T1 (test phase) to compare groups (control vs. overflow), sexes (male vs. female), hands (right vs. left), and phases (baseline vs. test). A multivariate analysis of variance (MANOVA) was conducted to evaluate main effects and interactions of group, sex, hand, and phase on HGS, with HGS for both hands as dependent variables. Significant MANOVA results were followed by post-hoc tests to identify specific differences ($p < 0.05$). Cohen's d was calculated to estimate effect sizes for between-group differences in HGS at T3.

RESULTS

Sample characteristics

Initially, 125 participants were contacted; however, 18 were excluded from the study because they were not right-handed (i.e., they were left-handed or ambidextrous). The final sample size was 107 participants who began the tests. Following the application of additional exclusions, a total of 90 subjects (45 per group) were subjected to analysis. Eight subjects from the control group and three subjects from the overflow group were excluded due to hand pain during the protocol, while six subjects from the overflow group were excluded for not reaching ≥70% of the MVIC in hip flexion in the ISSA assessment.

The control and overflow groups exhibited comparable anthropometric characteristics (weight: t= 0.127; height: t= 0.583) and homogeneous distribution by gender (χ^2= 0.776, p= 0.378). In the baseline phase, the initial HGS force was equivalent between the groups for men (C: 533.08 ± 95.63 N; O: 493.9 ± 90.56 N; t= 0.978) and women (C: 316.11 ± 63.82 N; O: 322.24 ± 60.08 N; t= -0.382) (Table 1).

Table 1. Characterization of the sample from the control and resistance groups

	Control (n= 45)	Overflow (n= 45)	Statistic Data
Age (years)	23.31±3.35	21.51±2.27	t=0.214
Weight (kg)	82.33±19.21	66.24±14.51	t=0.127
Height (cm)	168±8	168±9	t=0.583
Sex (M/F)	18/27	14/31	χ^2 =0.776
Male Strength (N)	533.08±95.63	493.9±90.56	t = 0.978
Female Strength (N)	316.11±63,82	322.24±60.08	t = -0.382

Sample Characterization. n: number of participants in each group; kg: kilograms; cm: centimetres; ±: standard deviation; t: result of the independent t-test comparing the two groups; M: Male subjects; F: Female subjects; N: Newtons; χ^2: chi-square test value for sex distribution between groups

Effects of Motor Overflow on Handgrip Strength

In the baseline phase, both groups demonstrated a significant decrease in HGS between the first trial (LB1) and the third trial

(LB3) in both hands (right and left), indicating a decline in muscle strength ($p<0.05$). In the experimental phase, the control group exhibited a significant decrease in HGS from T1 (100%) to T3 (left hand: $F(5,435)= 3.36$, $p<0.05$; right hand: $F(5,435)= 3.41$, $p<0.05$).

Meanwhile, the overflow group maintained T1 and T3 at statistical parity ($p>0.05$) in both hands (Figures 3A and 3B). The lack of statistical significance observed in the overflow group indicates the successful maintenance of strength. Effect size analysis using Cohen's d revealed a medium-to-large effect of motor overflow in maintaining HGS in the overflow group compared to the control group at T3 (d= 0.71 for left hand, d= 0.87 for right hand). These findings, estimated from reported group differences due to unavailability of raw data, underscore the clinical relevance of contralateral hip flexor activation in attenuating strength decline (Table 2).

Table 2. Handgrip Strength (HGS) Results for Control and Overflow Groups in Test Phase

Group	Hand	Sex	T1 (%)	T3 (%)	p-value	Cohen's d
Control	Left	Male	100	93.5 ± 5.8	<0.05	0.71
Overflow	Left	Male	100	98.5 ± 5.2	>0.05	
Control	Right	Male	100	92.0 ± 6.0	<0.05	0.87
Overflow	Right	Male	100	98.5 ± 5.3	>0.05	
Control	Left	Female	100	93.5 ± 5.8	<0.05	0.71
Overflow	Left	Female	100	98.5 ± 5.2	>0.05	
Control	Right	Female	100	92.0 ± 6.0	<0.05	0.87
Overflow	Right	Female	100	98.5 ± 5.3	>0.05	

*HGS expressed as percentage of T1 in the test phase, with estimated means ± standard deviations for T3, p-values from MANOVA, and Cohen's d for effect size based on group differences at T3. *p<0.05 indicates significant reduction from T1 to T3 in the control group; no significant reduction (p>0.05) in the overflow group. Note: T3 values are estimates derived from reported group differences due to unavailability of raw data*

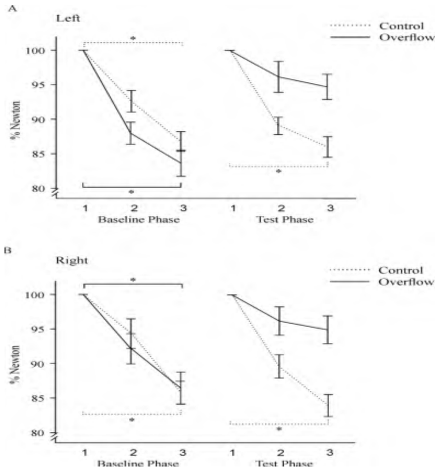
Influence of Sex on the Effects of Motor Overflow

Among the women, the control group exhibited a significant reduction in HGS in the test phase (left hand: $F(5,435)= 5.435$, $p<0.05$; right hand: $F(5,435)= 5.435$, $p<0.05$). In the overflow group, T1 and T3 remained statistically constant ($p>0.05$), suggesting that there was no decline in strength (Figures 4A and 4B).

For the male subjects in the control group, a significant decline was also observed (left hand: $F(5,425)= 3.79$, $p<0.05$; right hand: $F(5,425)= 3.79$, $p<0.05$). However, in the overflow group, HGS demonstrated stability (T1 and T3 were found to be equal, $p>0.05$) in both hands (Figures 5A and 5B). MANOVA revealed significant interactions between gender, group, and trials (left hand: $F(5,425)= 3.52$, $p= 0.0039$; right hand: $F(5,425)= 8.31$, $p<0.0001$). However, the pattern of force maintenance in the overflow group exhibited consistency for both men and women.

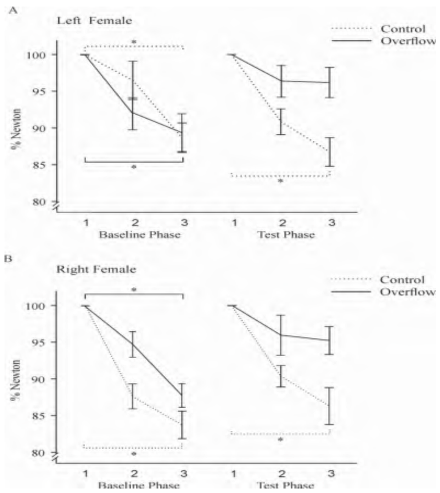
DISCUSSION

The findings of this study demonstrated that the simultaneous activation of the contralateral hip flexor in the overflow group led to a reduction in the decline in force generation that was imposed by the HGS force test. Specifically, the T1 and T3 values were found to be statistically equal ($p > 0.05$). In contrast, the control group exhibited a significant reduction ($p < 0.05$) in both hands and both sexes. This phenomenon suggests that motor overflow may counterbalance the processes linked to muscle fatigue, possibly through neural mechanisms that redistribute demand between cortical and spinal regions.



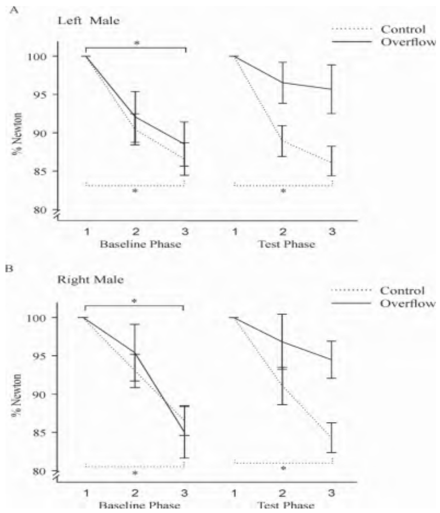
*The vertical axis represents the percentage of force generated in each trial. *p < 0.05 indicates significant differences when comparing the third trial to the first trial within each phase*

Figure 3. Force generated during trials in the control (dashed line) and overflow (solid line) groups on the left (A) and right (B) sides during the baseline and test phases



*The vertical axis represents the percentage of force generated in each trial. *p < 0.05 indicates significant differences when comparing the third trial to the first trial within each phase*

Figure 4. Force generated during trials by female subjects in the control (dashed line) and overflow (solid line) groups on the left (A) and right (B) sides during the baseline and test phases



*The vertical axis represents the percentage of force generated in each trial. *p < 0.05 indicates significant differences when comparing the third trial to the first trial within each phase*

Figure 5. Force generated during trials by male subjects' groups on the left (A) and right (B) sides during the baseline and test phases

Despite the absence of direct neurophysiological variable measurement, extant literature provides a foundation for hypothesizing the potential neural underpinnings of this mechanism.

The maintenance of HGS in the overflow group may be associated with the facilitation imposed by the corticospinal tract.[21]

Perez and Cohen[14] demonstrated that submaximal contractions in one hand increase the excitability of the contralateral corticospinal tract in homologous muscles, even at rest. However, the present study suggests that maximal contractions (>70% MVIC) can extend this effect to non-homologous muscles, such as the hip flexor and HGS. Research conducted by Benwell et al.[22] suggests that unilateral activation, even in rhythmic patterns, modulates corticospinal excitability via spinal circuits. This finding indicates that the hip flexor may influence HGS through segmental interactions that transcend cortical control.[23,24]

Hortobágyi et al.[25] further elaborate on this notion, demonstrating that contralateral contractions attenuate interhemispheric inhibition in the motor cortex. This mechanism may have contributed to the maintenance of force stability in the overflow group by facilitating motor output to the contralateral hand. Furthermore, Rossini et al.[26] have demonstrated that intense contractions (>70% MVIC) amplify contralateral corticospinal excitability, suggesting that the threshold reached in the hip flexor was sufficient to induce overflow in distal muscles. An alternative hypothesis posits that the phenomenon could be attributed to a reduction in cortical inhibition associated with fatigue. This theory is supported by documented findings from maximal repetitive tasks.[24] The overflow, as postulated, could counterbalance this reduction by recruiting alternative neural pathways.

The uniformity of this phenomenon across both male and female subjects in the overflow group lends further credence to the notion that overflow functions independently of initial muscle capacity, a distinction that is known to vary according to sex.[27,28] This finding suggests that the underlying mechanism may be more neural in nature than biomechanical, consistent with studies demonstrating comparable corticospinal adaptations between sexes in strength tasks.[28,29]

The present study diverges from conventional research in the field of motor overflow, which predominantly concentrates on homologous muscles (e.g., bilateral hands). Cleland et al.[13] observed involuntary activation in homologous muscles contralaterally during contractions above 70% of MVIC. However, our protocol explores non-homologous muscles (hip flexor and HGS), a less investigated aspect. In contrast to proprioceptive neuromuscular facilitation (PNF), which utilizes diagonal patterns involving triple flexion (ankle, knee, hip) to radiate force,[3,4,8] our approach involved isolating the hip flexor, thereby minimizing biomechanical contributions and emphasizing the neural component of overflow. Sharman et al.[3] posit that PNF depends on stretch reflexes and reciprocal inhibition. However, our protocol, by avoiding complex muscle chains, suggests that isolated activation of a proximal muscle may be sufficient to facilitate distal force.

This finding aligns with the concept of cross-education, which posits that unilateral training can enhance contralateral strength.[1,30] Calvert and Carson[1] have indicated that corticospinal and interhemispheric adaptations support this phenomenon; however, the present study has expanded upon this body of research by demonstrating that acute activation (not training) of a non-homologous muscle can attenuate fatigue in repetitive tasks.

In contrast to the observations reported by Lee et al.[7] who examined the phenomenon of force irradiation in diagonal upper limb exercises, our research concentrates on the proximal-distal (hip-hand) relationship, thereby providing a novel viewpoint on the induction of overflow without the necessity of employing broad motor patterns.[30]

The results of this study hold considerable implications for the field of neuromuscular rehabilitation. The capacity of overflow to attenuate the decline in force generation during repetitive tasks suggests its potential application in protocols for patients with muscle weakness or chronic fatigability, such as in peripheral neuropathies.[12] In contrast to PNF, which necessitates intricate coordination and may be impractical for certain patients [9], our streamlined approach—isolated activation of a proximate muscle—proffers a pragmatic alternative for augmenting distal strength without biomechanical strain. As demonstrated by Nakada et al.[12] ipsilateral PNF patterns have been shown to induce overflow in peripheral neuropathies. In contexts of limited mobility, our contralateral approach has the potential to complement this strategy.

Moreover, the stability of HGS in the overflow group, irrespective of gender, suggests that this strategy has the potential for wide application, ranging from athletes to the elderly.[22] Cronin et al.[15] emphasize the utility of HGS as a predictor of functional performance, and our protocol could be adapted for training or therapy, thereby prolonging functional capacity in repetitive tasks.

It is imperative to acknowledge the limitations of our study when interpreting the findings. The exclusion of 18 participants due to manual preference (not right-handed) and 11 dues to pain may have generated selection bias, limiting generalization to broader populations, such as left-handed people or individuals with variable pain tolerance.[17,18] The absence of neuroimaging (e.g., EMG, EEG) or electromyography prevents direct validation of the neural hypotheses, leaving them speculative based on references such as Perez and Cohen[14] and Benwell et al.[22] Furthermore, the emphasis on young, healthy adults (18-30 years) precludes insights into clinical or elderly populations, where fatigability and overflow may differ.[23]

Future research endeavors may seek to address these gaps in knowledge. Techniques such as electromyography (EMG) have been employed to measure corticospinal excitability during overflow in non-homologous muscles,[28] while electromyography has been used to quantify contralateral muscle activation.[27] Exploration of other muscle pairs (e.g., shoulder-wrist) or clinical conditions (e.g., cerebral palsy, spinal cord injuries) would broaden the applicability of the aforementioned methods.[5,10]

Psychological factors, including motivation and attention, are also a subject of interest, as they have the capacity to influence performance in maximal tasks.[24] In addition, the inclusion of left-handed or ambidextrous individuals, as previously suggested by Przybyla et al.[18] could provide valuable insights into the influence of laterality on overflow.

CONCLUSION

Our study advances neuromuscular control knowledge by elucidating motor overflow's influence on non-homologous muscles and limbs during a fatigability protocol, using isolated hip flexor activation as an experimental model. The findings of this study demonstrate the potential of overflow induction to mitigate fatigue-related strength decline. Our findings hold promise for developing novel rehabilitative interventions to enhance motor function and endurance in clinical populations.

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AUTORS' CONTRIBUTIONS

(Rosa GHM) methodology, investigation, formal analysis, writing – review & editing; (Moretto GH) methodology, investigation, formal analysis; (Zhang K, Chagas TJ) methodology, investigation, formal analysis; (Araujo JE) writing – review & editing, validation, supervision, project administration, conceptualization.

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