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Wpływ czasu trwania powtórzenia w ćwiczeniach oporowych na bezpośredni efekt treningowy

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1 WPROWADZENIE

Czas trwania powtórzenia jest sumą czasu trwania koncentrycznej, ekscentrycznej oraz izometrycznej fazy ruchu, określając rzeczywisty czas trwania wysiłku (Schoenfeld i wsp., 2015). Według badań naukowych wartość czasu trwania powtórzenia opisuje się za pomocą sekwencji trzech lub czterech liczb, w której każda liczba odpowiada danej fazie ruchu wyrażonej w sekundach (Schoenfeld i wsp., 2015; Wilk i wsp., 2018b). na przykład szereg liczb 3/1/2 lub 3/1/2/0 odpowiada 3-sekundowej fazie ekscentrycznej, 1-sekundowej fazie izometrycznej, 2-sekundowwej fazie koncentrycznej oraz w drugim przypadku brakiem zatrzymania w fazie przejściowej, jednocześnie rozpoczynającą kolejny cykl ruchowy (King, 2002; Wilk i wsp., 2018b; Wilk i wsp., 2020). Zmiana czasu trwania powtórzenia w ćwiczeniu oporowym może wynikać z narastającego zmęczenia lub wzrostu obciążenia zewnętrznego, którego wielkość wywołuje obniżenie prędkości sztangi w koncentrycznej fazie ruchu (Suchomel i wsp., 2019a; 2019b; Wilk i wsp., 2020). Jednak zmiana czasu trwania powtórzenia może być kontrolowana w świadomy, zaplanowany sposób, co w konsekwencji prowadzi do modyfikacji czasu trwania serii oraz całego ćwiczenia (Sakamoto i Sinclair, 2006; Wilk i wsp., 2018b). Czas trwania powtórzenia wyrażony jest przez czas trwania napięcia mięśniowego (Time Under Tension – TUT). Zatem wartość TUT w jednym powtórzeniu (repetition – REP) stanowi sumę trwania wszystkich faz ruchu (np. 1 REP w tempie powtórzenia 4/1/2/0 = 7 s). Natomiast podczas całej serii jest iloczynem liczby powtórzeń oraz czasu trwania powtórzenia (np. 4 REP w tempie 4/0/X/0 = 16 s, gdzie „X” określa maksymalną prędkość). Sugeruje to, że TUT może się różnić w zależności od liczby powtórzeń i czasu trwania powtórzenia, co z kolei może mieć istotny wpływ na objętość wysiłku fizycznego (Bird i wsp., 2005; Gumcio i wsp., 2015; Wilk i wsp., 2018a, 2018b).

Figueiredo i wsp. (2018) sugerują, że objętość wysiłku jest zmienną najbardziej modyfikowalną, która znacząco wpływa na rozwój siły i hipertrofii mięśniowej (Schoenfeld i wsp., 2015; 2016; 2017), przez reakcje adaptacyjne w układzie nerwowo-mięśniowym (Häkkinen i wsp., 1985), reakcje metaboliczne (Ratamess i wsp., 2007) oraz hormonalne (Gotshalk i wsp., 1997; Häkkinen i Pakarinen, 1995; Kraemer i wsp., 1985). Dotychczasowe badania naukowe określają objętość wysiłku fizycznego wyrażoną zwykle na podstawie sumy liczby wykonanych powtórzeń. Jednakże jedno powtórzenie może trwać od 2 do nawet kilkunastu sekund, czego dotychczasowy sposób określania objętości wysiłku nie bierze pod uwagę (Wilk i wsp., 2018b). Badania potwierdziły, że nie tylko zmiana czasu trwania pełnego powtórzenia wpływa na zmianę maksymalnej liczby powtórzeń oraz wartość TUT w serii, ale również zmiana czasu trwania tylko jednej fazy ruchu (ekscentrycznej, izometrycznej, bądź koncentrycznej) wpływa na wartość objętości wysiłku, a tym samym może mieć istotny wpływ na rozwój hipertrofii mięśniowej, generowanie mocy mięśniowej oraz poziom bezpośrednich powysiłkowych reakcji metabolicznych i hormonalnych (Goto i wsp., 2008; Headley i wsp., 2011; Schoenfeld i wsp., 2015; Tanimito i Ishii, 2006; Watanabe i wsp., 2013; Westcott i wsp., 2001; Wilk i wsp., 2018b, 2020b). na przykład w serii liczącej 8 powtórzeń, gdy czas trwania jednego powtórzenia wynosi 4s (2/0/2/0), wartość TUT wynosi 32s. Stosując tę samą liczbę powtórzeń, kiedy czas trwania jednego z nich wynosi 6s (4/0/2/0) spowoduje, że wartość TUT wrasta aż do 48s. Wysiłek z wykorzystaniem dłuższego tempa powtórzenia, a tym samym wyższej wartości TUT może ograniczyć liczbę powtórzeń możliwych do wykonania podczas serii (Sakamoto i Sinclair, 2006; Wilk i wsp., 2018b, 2018b). Spośród wielu badań naukowych w zakresie kształtowania siły i mocy mięśniowej niewiele z nich w procedurze badawczej zastosowało świadomą kontrolę czasu trwania powtórzenia (Hatfield i wsp., 2006; Headley i wsp., 2011; Sakamoto i Sinclair, 2006; Westcott i wsp., 2001; Wilk i wsp., 2018a, 2018b, 2019).

Dłuższy czas trwania powtórzenia (np. 6/0/X/0) może ograniczyć także aktywność nerwowo-mięśniową oraz efekt cyklu rozciągnięcie-skurcz, negatywnie oddziałując na poziom generowanej mocy mięśniowej w fazie koncentrycznej (Wilk i wsp., 2019a), w porównaniu do krótszego czasu trwania powtórzenia (2/0/X/0). Niższe zapotrzebowanie energetyczne w ekscentrycznym skurczu mięśniowym powoduje, że stosunek czasu trwania fazy ekscentrycznej do fazy koncentrycznej może mieć istotny wpływ na maksymalną wartość liczby powtórzeń oraz czasu trwania napięcia mięśniowego w serii (Enoka, 1996; Roig i wsp., 2010). Wykazano, że zmniejszenie liczby powtórzeń podczas stosowania tempa powtórzenia (6/0/4/0) powoduje jednoczesny wzrost wartości TUT, w porównaniu do tempa powtórzenia (2/0/2/0) (178.89 ± 33.69 s vs. 124.65 ± 33.66 s; kolejno) (Wilk i wsp., 2018b). Tym samym niższa liczba powtórzeń niekoniecznie oznacza krótszy czas trwania wysiłku, a wręcz przeciwnie pozwala na realizację wysiłku przez istotnie dłuższy czas. Wydłużenie czasu trwania napięcia mięśniowego może prowadzić do wyższych powysiłkowych reakcji fizjologicznych (Burd i wsp., 2012; Koegh i wsp., 1999; Wilk i wsp., 2018a, 2018b, 2019b) oraz większego poziomu obserwowanych uszkodzeń mięśniowych (Schoenfeld i wsp., 2015). Wyższy poziom uszkodzeń mięśniowych wywołanych wysiłkiem fizycznym zwiększa aktywację komórek satelitarnych mających istotny udział w procesie regeneracji oraz hipertrofii komórek mięśniowych (Fridén i wsp., 1983; Stauber i wsp., 1988). Ponadto, dłuższa wartość TUT w serii wywołana zastosowaniem dłuższego czasu trwania powtórzenia (np. 6/0/6/0) wpływa na wyższą syntezę białek mitochondrialnych, sarkoplazmatycznych i miofibryllarnych (Burd i wsp., 2012) oraz zwiększa poziom stresu metabolicznego, przyczyniając się do zwiększonej odpowiedzi hipertroficznej (Fridén i wsp., 1983; Stauber i wsp., 1988; Hutchins, 1992; Burd i wsp., 2012), w porównaniu z krótszą wartością TUT w serii i w jednostce treningowej. Wartości TUT, która wpływa na poziom objętości treningowej może być ważnym czynnikiem stymulującym bezpośrednie powysiłkowe reakcje metaboliczne i hormonalne.

Do kluczowych hormonów wpływających na zmiany adaptacyjne ukierunkowane na hipertofię i siłę mięśniową należą: testosteron, hormon wzrostu (GH), kortyzol oraz insulinopodobny czynnik wzrostu (IGF-1) (Wilk i wsp., 2020). Objętość oraz intensywność wysiłku powinny być właściwie zaplanowane, aby ograniczać poziom powysiłkowego stężenia kortyzolu, jednocześnie uzyskując powysiłkowy wzrost stężenia testosteronu, GH i IGF-1 (Wilk i wsp., 2018a, 2021). Dotychczasowe badania naukowe wskazują, że na wyższy powysiłkowy poziom mleczanu oraz GH wpływa czas trwania przerwy wypoczynkowej pomiędzy seriami (Bottaro i wsp., 2009; Buresh i wsp., 2009; Rahimi i wsp., 2010), objętość wysiłku (Gotshalk i wsp., 1997; Leite i wsp., 2011), intensywność wysiłku (Goto i wsp., 2008; Raastad i wsp., 2000) oraz czas trwania powtórzenia (Goto i wsp., 2009). Uchida i wsp. (2009) oceniali poziom reakcji metabolicznych i hormonalnych po wykonaniu wyciskania sztangi leżąc w czterech próżnych protokołach badawczych (4 serie 50% 1-RM, 5 serii 75% 1-RM, 10 serii 90% 1-RM oraz 8 serii 110% 1-RM), w których każdy protokół został zrównany z objętością wysiłku (liczba powtórzeń x liczba serii x wartość obciążenia zewnętrznego). Autorzy wykazali niewielkie powysiłkowe różnice zmiany stężenia testosteronu i kortyzolu pomiędzy protokołami ($p > 0.005$), jednak najwyższy poziom kortyzolu zauważono w protokole, w którym zastosowano 5 serii z 75% 1-RM (Uchida i wsp., 2009). Headley i wsp. (2011) analizowali wpływ tempa powtórzenia 2/0/2/0 oraz 4/0/2/0 na reakcje metaboliczne i hormonalne w wyciskaniu sztangi leżąc wśród mężczyzn zaawansowanych w treningu oporowym. Autorzy wykazali wzrost w powysiłkowym poziomie IGF-1 (tempo powtórzenia 2/0/2/0 przed treningiem: 277.4 ± 21.8, po treningu: 308.1 ± 22.9; tempo powtórzenia 4/0/2/0 przed treningiem: 277.2 ± 17.6, po treningu: 284.8 ± 21.2 ng/ml), natomiast nie zauważono różnic w powysiłkowym poziomie mleczanu, testosteronu, GH oraz kortyzolu między protokołami badawczymi. w przeciwieństwie do tego Goto i wsp. (2008) wykazali wyższe zmiany stężenia testosteronu, hormonu wzrostu oraz kortyzolu po zastosowaniu treningu oporowego z dłuższym czasem trwania powtórzenia (3/0/3/0), w przeciwieństwie do krótkiego czasu trwania powtórzenia (1/0/1/0). Wilk i wsp. (2018a) wykazali wyższy powysiłkowy poziom mleczanu, kinazy kreatynowej oraz testosteronu po protokole, w którym badani wykonali pięć serii z maksymalną liczbą powtórzeń wyciskania sztangi leżąc z obciążeniem 70% 1-RM w tempie 6/0/2/0, w przeciwieństwie do tempa powtórzenia 2/0/2/0. Badanie to sugeruje, że celowe wydłużenie czasu trwania fazy ekscentrycznej w ćwiczeniu oporowym zmniejsza liczbę powtórzeń możliwą do wykonania, ale może wywołać zwiększoną powysiłkową odpowiedź hormonalną. Co więcej Wilk i wsp. (2021) udowodnili, że dłuższy czas trwania powtórzenia (6/0/2/0 vs. 2/0/2/0) podczas przysiadu ze sztangą powodował wzrost powysiłkowego poziomu mleczanu, kinazy kreatynowej oraz testosteronu. Autorzy sugerują, że wolniejsze tempo powtórzenia (6/0/2/0) może zmniejszyć liczbę powtórzeń możliwą do wykonania, ale poprzez wydłużenie całkowitej wartości TUT zwiększa powysiłkowe reakcje hormonalne w treningu oporowym (Wilk i wsp., 2021). Podobnie Goto i wsp. (2009) wykazali wyższy poziom testosteronu oraz GH, kiedy czas trwania powtórzenia został wydłużony (1/0/1/0 vs. 3/0/3/0 vs. 1/0/5/0 vs. 5/0/1/0). Co więcej autorzy dowiedli, że ćwiczenia o niskiej intensywności z dłuższym czasem trwania ekscentrycznej fazy ruchu (5s) powodowały mniejsze zmiany stężenia mleczanu oraz kortyzolu, w porównaniu z ćwiczeniami o niskiej intensywności z dłuższym czasem trwania fazy koncentrycznej (5s) (Goto i wsp., 2009). Potwierdził to Calixto i wsp. (2014), którzy wykazali wyższe powysiłkowe stężenie mleczanu oraz GH w grupie, która wykonywała dłuższą fazę ekscentryczną (3s vs. 0.5s). Natomiast Durand i wsp. (2003) porównali poziom powysiłkowych wartości hormonalnych między koncentryczną, a ekscentryczną pracą mięśni przy stałym obciążeniu zewnętrznym (80% 1-RM). Autorzy wykazali, że koncentryczne działanie mięśni zwiększa stężenie hormonu wzrostu w znacznie większym stopniu, niż ćwiczenia w pracy ekscentrycznej, natomiast wyższy poziom GH wynikał raczej z intensywności wysiłku, a nie z pracy mięśnia (Durand i wsp., 2003).

Tempo powtórzenia jako zmienna treningowa, stosowane jest najczęściej w niekontrolowany sposób. Brakuje badań analizujących objętość wysiłku w treningu oporowym wykorzystując celowy, świadomy czas trwania powtórzenia w każdej fazie ruchu. Ponadto zmiana czasu trwania powtórzenia w treningu oporowym może wpłynąć na wartość generowanej mocy mięśniowej, siłę maksymalną czy powysiłkową odpowiedź metaboliczną i hormonalną. w przedstawionym cyklu prac głównym problemem badawczym jest ocena wpływu i wykorzystania różnych wartości czasu trwania powtórzenia w procesie adaptacji treningowej. Dokonano analizy i oceny wpływu zmiennego czasu trwania powtórzenia na wartości objętości wysiłku, maksymalnej siły mięśniowej, generowanej mocy mięśniowej oraz powysiłkowych reakcji hormonalnych i metabolicznych. Prace te zostały przedstawione pod wspólnym tematem:

„Wpływ czasu trwania powtórzenia w ćwiczeniach oporowych na bezpośredni efekt treningowy”. Celem przedstawionego cyklu czterech prac jest analiza następujących zagadnień:

1 – porównanie różnej długości kontrolowanego czasu trwania powtórzenia w wyciskaniu sztangi leżąc na objętość wysiłku ocenianej na podstawie wartości TUT i liczby powtórzeń między osobami początkującymi, a zaawansowanymi,

2 – analiza i ocena wpływu zmiany czasu trwania fazy ekscentrycznej ruchu przy zastosowaniu różnych szerokości chwytu sztangi w wyciskaniu leżąc na poziom mocy mięśniowej i prędkości sztangi w fazie koncentrycznej,

3 – analiza i ocena wpływu czasu trwania fazy ekscentrycznej ruchu na wynik testu siły maksymalnej podczas wyciskania sztangi leżąc,

4 – analiza i ocena wpływu czasu trwania powtórzenia na poziom powysiłkowych reakcji endokrynnych.

2 PRZEDMIOT ROZPRAWY

Przedmiotem rozprawy doktorskiej jest zbiór publikacji przedstawiony jako jednotematyczny cykl czterech prac, opublikowanych w czasopismach, z których trzy posiadają wskaźnik Impact Factor, zgłębiających wpływ czasu trwania powtórzenia w ćwiczeniu oporowym na wartość objętości treningowej. Łączna wartość punktowa opublikowanych prac wynosi: **IF = 7,196; MNSiW = 260 pkt KBN.**

Prace zostały przedstawione pod wspólnym tematem: „Wpływ czasu trwania powtórzenia w ćwiczeniach oporowych na bezpośredni efekt treningowy"

Wykaz prac opublikowanych:

1. Adam Maszczyk, Michał Wilk, Michał Krzysztofik, **Mariola Gepfert,** Adam Zając, Miroslav Petr, Petr Stastny. *The effects of resistance training experience on movement characteristics in the bench press exercise.* Biology of Sport Vol. 37, nr 1 (2020), s. 79-83.

   [IF = 2.00; MNiSW = 70]

2. **Mariola Gepfert,** Aleksandra Filip, Maciej Kostrzewa, Paulina Królikowska, Grzegorz Hajduk, Robert Trybulski, Michał Krzysztofik. *Analysis of power output and bar velocity during various techniques of the bench press among women.* Journal of Human Sport and Exercise Vol. 16, nr 1 (2021), s. 1-9.

   [MNiSW = 20]

3. Michal Wilk, **Mariola Gepfert,** Michał Krzysztofik, Aleksandra Mostowik, Aleksandra Filip, Grzegorz Hajduk, Adam Zając. *Impact of duration of eccentric movement in the one-repetition maximum test result in the bench press among women.* Journal of Sports Science and Medicine Vol. 19 (2020), s. 317-322.

   [IF = 1.806; MNiSW = 100]

4. **Mariola Gepfert,** Robert Trybulski, Petr Stastny, Michał Wilk. *Fast eccentric movement tempo elicits higher physiological responses than medium eccentric tempo in ice-hockey players.* International Journal of Environmental Research and Public Health Vol. 18 (2021), s. 1-14.

   [IF = 3.390; MNiSW = 70]

PRACA NR 1

„The effects of resistance training experience on movement characteristics in the bench press exercise"

Pierwszym badaniem dotyczącym oceny wpływu tempa powtórzenia na objętość wysiłku w treningu oporowym była praca: *„The effects of resistance training experience on movement characteristics in the bench press exercise"* opublikowana w czasopiśmie *„Biology of Sport"*. Głównym celem badania było ustalenie czy poziom doświadczenia w treningu oporowym ma istotny wpływ na różnice w objętości wysiłku określanej na podstawie liczby powtórzeń oraz wartości TUT stosując określony, kontrolowany czas trwania powtórzenia. w badaniu uczestniczyło 68 mężczyzn, których podzielono na grupę początkującą i zaawansowaną. Grupa początkująca składała się z 32 osób (18-32 lat; masa ciała: 69.9 ± 5.7 kg; 1-RM: 67.3 ± 6.9 kg), została przeszkolona w zakresie techniki wyciskania sztangi leżąc oraz wykonała trzy jednostki treningowe w ciągu dwóch tygodni, przed jednostką eksperymentalną. do grupy zaawansowanej zakwalifikowano 36 osób (20-38 lat; masa ciała: 81.2 ± 6.7 kg; 1-RM: 112.3 ± 12.5 kg), z co najmniej dwuletnim doświadczeniem w treningu oporowym (3.7 ± 0.92). Sesja eksperymentalna zakładała wykonanie 5 serii wyciskania sztangi leżąc, stosując 70% 1-RM wartości obciążenia zewnętrznego oraz 3-minutowe przerwy wypoczynkowe między seriami. Procedura badawcza zakładała porównanie kontrolowanego, zmiennego czasu trwania powtórzenia w fazie ekscentrycznej i koncentrycznej ruchu: 2/0/2/0, 5/0/3/0 oraz 6/0/4/0. Hipoteza badawcza zakładała, że zarówno czas trwania powtórzenia, jak i doświadczenie w treningu oporowym znacząco wpływa na maksymalną liczbę powtórzeń oraz wartość TUT. do oceny objętości wysiłku zastosowano sumę liczby powtórzeń oraz TUT zarówno w serii, jak i w całej jednostce eksperymentalnej.

Wyniki badania wykazały, że występują różnice istotne statystycznie w maksymalnej wartości TUT w wyciskaniu sztangi leżąc pomiędzy grupą początkującą, a zaawansowaną stosując różne tempo powtórzenia. Istotne różnice pomiędzy grupą początkującą i zaawansowaną wykazano podczas długiego czasu trwania powtórzenia (6/0/4/0) w pierwszej ($p = 0.01$) i w drugiej serii ($p = 0.04$) oraz podczas krótkiego czasu trwania powtórzenia (2/0/2/0) w piątej serii ($p = 0.01$). Ponadto potwierdzono znaczące różnice dla sumy TUT między grupą początkującą, a zaawansowaną w procedurze zawierającej długi czas trwania powtórzenia 6/0/4/0 (p = 0.04). Co więcej badania wykazały istotne różnice również w liczbie REP między grupami dla długiego czasu trwania powtórzenia (6/0/4/0) w czwartej (p = 0.04) i piątej serii (p = 0.04) oraz dla krótkiego czasu trwania powtórzenia (2/0/2/0) w piątej serii ćwiczenia (p = 0.01).

Badania dowiodły, że zarówno poziom doświadczenia w treningu oporowym, ale przede wszystkim czas trwania powtórzenia, ma znaczący wpływ na objętość wysiłku zarówno pod względem wartości TUT, jak i liczby powtórzeń. Należy zauważyć, że istotne różnice między grupami w sumie TUT w 5 seriach, zauważono jedynie przy długim czasie trwania powtórzenia (6/0/4/0). w niniejszym badaniu czas trwania wolnego powtórzenia (6/0/4/0) wynosił aż 10s, natomiast odmowa mięśniowa mogła wystąpić w dowolnym momencie ćwiczenia np. przez brak umiejętności wykonania pełnego zakresu ruchu, utrzymania prawidłowego tempa ruchu lub prawidłowej techniki, co można było odnotować jedynie na podstawie wartości TUT, a nie liczby powtórzeń. Dodatkowo badania wykazały istotne różnice w wartości sumy TUT między grupą początkującą, a zaawansowaną w treningu oporowym. Co ciekawe, grupa zaawansowana uzyskała niższą wartość sumy TUT w 5 seriach (178 s ± 33 s), w porównaniu z grupą początkującą (203.8 s ± 33.9 s). w przeciwieństwie do wartości TUT, nie wykazano istotnej różnicy w wartości całkowitej liczby powtórzeń w pięciu seriach między grupami. Zatem objętość wysiłku może być uwarunkowana przez czas trwania powtórzenia w ćwiczeniu oporowym. Wyniki przeprowadzonych badań są zgodne z wytycznymi Wilka i wsp. (2018b), potwierdzając tym samym przydatność określania objętości wysiłku za pomocą wartości TUT, a nie tylko liczby powtórzeń. Czas trwania jednego powtórzenia zależy od czasu poszczególnych faz ruchu. w przeciwieństwie do wartości liczby powtórzeń, TUT precyzyjniej określa czas wykonanej pracy szczególnie wtedy, gdy stosowany jest dłuższy czas trwania powtórzenia. w przypadku analizy objętości wysiłku na podstawie sumy powtórzeń, brak wykonania pełnego cyklu ruchowego stosując dłuższe tempo powtórzenia (6/0/4/0), nawet jeśli osoba badana wykonała 8-9s pracy, skutkowała brakiem odnotowanego powtórzenia, co ogranicza wiarygodność takich pomiarów. Zasadność oceny objętości wysiłku na podstawie wartości TUT w serii i w całym ćwiczeniu dotyczy dowolnej długości trwania powtórzenia. Co ważniejsze, w badaniu nie stwierdzono istotnych różnic w wartości TUT w krótkim (2/0/2/0) oraz w średnim (5/0/3/0) czasie trwania powtórzenia, co może sugerować, że tylko ćwiczenie z wykorzystaniem ekstremalnie długiego czasu trwania powtórzenia różnicuje objętość wysiłku, w zależności od poziomu doświadczenia w treningu oporowym. Ponadto wartość liczby powtórzeń nie wykazała żadnych istotnych różnic zarówno w pojedynczej serii, jak i w całym ćwiczeniu, niezależnie od analizowanego czasu trwania powtórzenia. Wyniki badań wartości TUT, są zgodne z wcześniejszymi doniesieniami, które wskazywały, że tempo powtórzenia w ćwiczeniu oporowym wpływa na objętość wysiłku (Hatfield i wsp., 2006; Hutchins, 1993; Westcott i wsp, 2001; Wilk i wsp., 2018a, 2018b; 2019b). Co więcej, wyniki wykazują zgodność z badaniami Wilka i wsp. (2018b, 2019b), którzy wskazali, że wartość TUT jest dokładniejszym wyznacznikiem objętości wysiłku, w porównaniu z wartością liczby powtórzeń. Jednak, aby lepiej zrozumieć wpływ czasu trwania powtórzenia w ćwiczeniu oporowym należy rozszerzyć procedurę badań o dodatkowe wartości ze szczególnym uwzględnieniem generowanej mocy mięśniowej.

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The effects of resistance training experience on movement characteristics in the bench press exercise

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ABSTRACT: The main aim of this study was to determine whether the level of experience in strength training has a significant effect on differences in the value of exercise volume determined on time under tension (TUT) and number of repetition (REP) for a specific movement tempo. The study examined 68 men divided into groups of beginners and advanced strength trained athletes. The participants performed 5 sets of bench press (BP) at 70% 1RM using either a REG, MED or SLOW metronome guided cadence. Each set was performed to failure and with 3 min of rest between sets. Significant differences in TUT were found between the groups of beginners and advanced athletes for the slow (SLO) 6/0/4/0 tempo in set 1 ($p = 0.01$) and set 2 ($p = 0.04$), and for the regular (REG) 2/0/2/0 tempo in set 5 ($p = 0.01$). Significant differences were documented for total TUT between the beginners and advanced athletes for the SLO 6/0/4/0 tempo ($p = 0.04$). The results of ANOVA revealed significant differences in the number of repetitions between groups for the SLO 6/0/4/0 tempo in set 4 ($p = 0.04$) and set 5 ($p = 0.04$), and for the REG 2/0/2/0 tempo in set 5 ($p = 0.01$). The main finding of this study is that strength training experience has a significant effect on training volume, both in terms of TUT and REP at a specific constant movement tempo. Significant differences do not occur for each value of the tempo used.

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INTRODUCTION

Strength training is one of the most popular forms of physical activity. Physical exercise with external loads can be used at almost any age, by young people and older adults, people with training experience and beginners. Regardless of who performs the physical exercise, programming training loads is connected with determination of the volume and intensity of exercise. Volume and intensity of training depend on individual components of strength training, with each component having both, acute and chronic effects on adaptation [1]. Principal variables of resistance training include the value of external load, often synonymous with intensity (%1RM), number of repetitions, sets, duration of rests intervals between sets [2–4]. More and more often, the examinations related to strength training analyse the impact of movement tempo in resistance training on exercise volume, increase in muscular strength and power or hypertrophy [5–13]. The term tempo relates to the rate at which each repetition is performed. Movement tempo and cadence are most often defined by means of several digits which correspond to individual movement phases. For example, 6/0/3/0 denotes a 6-second eccentric phase, no break in the transition phase, a 3-second concentric phase and no rest before the next repetition [8]. Changes in tempo, and consequently, the velocities in individual phases of the movement, can results from the effect of the external resistance, with the increase in the external load leading to the decline in maximal movement speed in the concentric phase [9] or conscious control of individual movement cadences, which has been the topic of recent research [12]. Tempo, i.e. duration of a single repetition, determines time under tension (TUT) for a set and, in total, for a training session [12]. The TUT value for a particular exercise has an effect on exercise volume and the value of post-exercise metabolic and endocrine adaptations [2,13]. Exercise volume represents one of the most critical elements of the adaptation process, not only in regards to muscular strength, but also in the development of other motor abilities. In strength training, exercise volume has been evaluated based on the number of repetitions or, as suggested by Wilk et al. [12], based on the TUT values. A study by Wilk et al. [12] showed that the change in movement tempo in strength training impacts significantly on the volume of exercise, both in terms of the number of completed REP and TUT values. Movement tempo in strength training also determines the value of generated muscle force [4,11,14] and number of repetitions that can be completed in a set [10,12,13]. Furthermore, slow movement tempo leads to higher post-exercise fatigue and a greater decline in muscle power compared to volitional tempo [5]. These findings show that slower movement tempo and, consequently, potentially lower exercise volume (if it is defined based on REP) can place a greater load on the human body compared to training with conventional movement tempo and greater training volume (REP). However, if training volume is defined according to the guidelines by Wilk et al. [12,13] based on TUT, the use of slow movement tempo allows the athlete to significantly extend TUT and, consequently, increase training volume. Longer time of sustained muscle tension in a set can be also useful in evoking muscle hypertrophy [15,16] which can be linked to e.g. the fact that slow movement extends the time under tension without the relaxation phase [17,18]. Some previous studies showed also that maximal power production depends on training status [19] and motivation state [20].

All previous studies that have analysed the effect of movement tempo or cadence of individual movement phases on the level of acute or chronic adaptations focused on the analysis of a specific homogenous research group. However, training effects depend not only on the value of particular training variables, including movement tempo, but also on the experience of the people who perform the resistance training programs. Since previous studies have confirmed that movement tempo impacts exercise volume significantly, the number of completed REP, time under tension (TUT) and levels of muscle force and power [4,5,10–14] in this study we attempted to verify whether there are significant differences in exercise volume evaluated based on TUT and REP for specific movement tempo between novice and advanced strength trained subjects. To date, it has not been demonstrated whether the level of response at constant movement tempo is the same in groups of beginners and advanced strength trained subjects.

MATERIALS AND METHODS

All testing was performed in the Strength and Power Laboratory at the Jerzy Kukuczka Academy of Physical Education in Katowice. The experiment was performed following a randomized crossover design, where each participant performed a familiarization session with a 1-RM test and three different testing protocols a week apart. During the experimental sessions, subjects performed five sets of the bench press exercise to concentric failure using 70% 1RM and three different tempos: 2/0/2/0 regular tempo (REG), 5/0/3/0 medium tempo (MED) and 6/0/4/0 slow tempo (SLO). Subjects were required to refrain from resistance training 72 hours prior to each experimental session, were familiarized with the exercise protocol and were informed about the benefits and risks of the examinations before expressing their written consent for participation in the study.

Study participants

The study examined 68 men divided into groups of beginners and advanced strength trained athletes. The novice group included 32 men (18–32 yrs, 69.9 ± 5.7 kg, 67.3 ± 6.9 kg bench press 1RM). Before the examinations, the novice group was trained in terms of bench press technique and performed three strength training sessions in two weeks prior to the examinations dedicated to the bench press technique with a specific movement tempo. The advanced group comprised of 36 men, (20–38 yrs, 81.2 ± 6.7 kg, 112.3 ± 12.5 kg bench press 1RM) with a minimum of two years of strength training experience (3.7 ± 0.92 years). All subjects were over 18 years old. The participants were allowed to withdraw from the experiment at any moment and were free of any pathologies or injuries. The protocol of examinations and written consent of participants were approved by the Bioethics Committee at the Academy of Physical Education in Katowice, Poland, according to the ethical standards of the Declaration of Helsinki, 1983. Subjects were instructed to maintain their normal dietary habits for the duration of the study period and did not use any dietary supplements or stimulants for the duration of the experiment.

Procedures

Familiarization session and one repetition maximum test

The participants arrived at the laboratory at the same time of day as the upcoming experimental sessions (in the morning between 09:00 and 11:00) and cycled on an ergometer for 5 minutes at an intensity that resulted in a heart rate of around 130 bpm, followed by

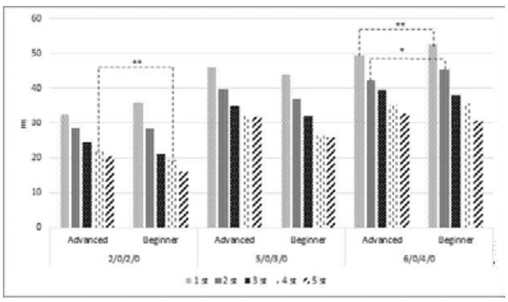

FIG. 1. TUT for 2/0/2/0, 5/0/3/0 and 6/0/4/0 tempos in sets 1–5 between beginner and advanced groups.

Note: ** p< .01, *p<.05

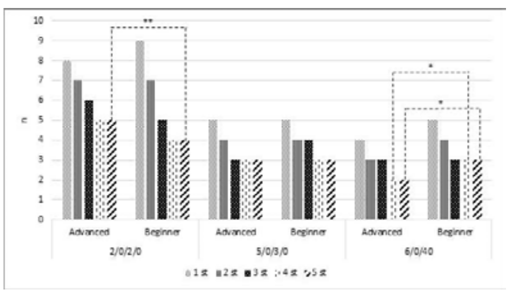

FIG. 2. REP for 2/0/2/0, 5/0/3/0 and 6/0/4/0 tempos in sets 1–5 between beginner and advanced groups.

Note: ** p< .01, *p<.05

a general upper body warm-up of 10 body weight pull ups and 15 body weight push-ups. Next, the participants performed 15, 10, and 5 BP repetitions using 20kg, 40%, and 60% of their estimated 1RM using a 2/0/2/0 cadence. Hand placement on the barbell was individually selected, but the forefinger had to be inside of the 81-cm mark on a standard Olympic bar. The positioning of the hands was recorded to ensure consistent hand placement during all testing sessions. The participants then executed single repetitions using a volitional cadence with a 5 min rest interval between successful trials. The load for each subsequent attempt was increased by 2.5 kg, and the process was repeated until failure.

Experimental sessions

The participants arrived at the laboratory in the morning (09:00 to 11:00). After completing the same warm-up as in the previous session, the participants performed 5 sets of BP at 70% 1RM using either a REG, MED or SLOW metronome guided cadence (Korg MA-30, Korg, Melville, New York, USA). Each set was performed to failure and with 3 min of rest between sets. The participants were verbally encouraged throughout all testing sessions. All repetitions were performed without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases, and without raising the lower back off the bench.

Statistical analysis

All the statistical analyses were performed using the STATISTICA software version 12 (StatSoft, Inc.) at $\alpha = .0.05$. The data were tested for normal distribution using the Shapiro-Wilk test. In order to establish whether the differences occurred for the number of repetitions and TUT between the beginner group and advanced athletes for the REG 2/0/2/0, MED 5/0/3/0 and SLO 6/0/4/0 tempos and series 1–5, the analysis of variance (ANOVA) was performed and post-hoc Tukey's tests were continued. The F statistic and level of significance were evaluated. Homogeneity of variance was verified and met using the Levene's test at $p > 0.05$.

RESULTS

The data had a normal distribution (W range between 0.80 and 0.99). Significant differences in TUT were found between the groups of beginners and advanced athletes for the SLO 6/0/4/0 tempo in set 1 ($p = 0.01$) and set 2 ($p = 0.04$), and for the REG 2/0/2/0 tempo in set 5 ($p = 0.01$) (Tabs. 1 and 3, Fig. 1). Furthermore, significant differences were documented for total TUT between the beginners and advanced athletes for the SLO 6/0/4/0 tempo ($p = 0.04$) (Tab. 3). The ANOVA also revealed significant differences in the number of repetitions between groups for the SLO 6/0/4/0 tempo in set 4 ($p = 0.04$) and set 5 ($p = 0.04$), and for the REG

TABLE 1. TUT in particular sets of the BP for REG 2/0/2/0, MED 5/0/3/0 and SLO 6/0/4/0 tempos in the beginner and advanced groups.

Set	Advanced			Beginner		
	2/0/2/0	5/0/3/0	6/0/4/0	2/0/2/0	5/0/3/0	6/0/4/0
1st	32.52 (±8.10)	45.95 (±15.62)	49.53 (±17.02)**	35.85 (±9.18)	43.88 (±15.44)	52.53 (±10.19)**
2nd	28.52 (±8.50)	39.80 (±16.21)	42.41 (±17.19)*	28.30 (±7.50)	37.11 (±8.25)	45.39 (±10.53)*
3rd	24.43 (±7.02)	34.90 (±17.00)	39.41 (±17.77)	20.90 (±5.78)	32.17 (±7.33)	38.17 (±6.88)
4th	21.61 (±7.48)	32.15 (±17.61)	35.29 (±18.54)	19.25 (±4.70)	26.17 (±6.35)	35.61 (±5.93)
5th	20.41 (±6.22)**	31.80 (±17.75)	32.76 (±19.17)	15.90 (±5.04)**	25.78 (±8.34)	30.72 (±3.41)

Note: ** p< .01, *p<.05

TABLE 2. REP in particular sets for each 2/0/2/0, 5/0/3/0 and 6/0/4/0 tempos in the beginner and advanced groups.

Set	Advanced			Beginner		
	2/0/2/0	5/0/3/0	6/0/4/0	2/0/2/0	5/0/3/0	6/0/4/0
1st	8 (±2)	5 (±1)	4 (±1)	9 (±2)	5 (±1)	5 (±1)
2nd	7 (±2)	4 (±1)	3 (±1)	7 (±1)	4 (±1)	4 (±1)
3rd	6 (±1)	3 (±1)	3 (±1)	5 (±1)	4(±1)	3 (±1)
4th	5 (±1)	3 (±1)	2 (±1)*	4 (±1)	3 (±1)	3 (±1)*
5th	5 (±1)**	3 (±1)	2 (±1)*	4 (±1)**	3 (±1)	3 (±1)*

Note: ** p< .01, *p<.05

TABLE 3. Total TUT for particular 2/0/2/0, 5/0/3/0 and 6/0/4/0 tempos in the beginner and advanced groups

Total TUT	Group		Anova	
	Advanced	**Beginner**	**F**	**p**
2/0/2/0	124 (±33)	123 (±28)	0.02	0.89
5/0/3/0	166 (±29)	166 (±31)	0.01	0.99
6/0/4/0	178 (±33)	203.8 (±33.9)	*4.76*	*0.04*

TABLE 4. Total REP for particular 2/0/2/0, 5/0/3/0 and 6/0/4/0 tempos in the beginner and advanced groups

Total REP	Group		Anova	
	Advanced	**Beginner**	**F**	**P**
2/0/2/0	28 (±7)	28 (±6)	0.02	0.89
5/0/3/0	18 (±4)	18 (±3)	0.26	0.61
6/0/4/0	15 (±4)	17 (±4)	2.19	0.15

2/0/2/0 tempo in set 5 ($p = 0.01$) (Tabs. 2 and 4, Fig. 2). The total number of repetitions for individual REG 2/0/2/0, MED 5/0/3/0 and SLO 6/0/4/0 tempos did not differ significantly between groups ($p > 0.05$) (Tab. 4).

DISCUSSION

The main finding of the study is that the level of strength training experience has a significant effect on training volume both in terms of TUT and REP at a specific constant movement tempo. However, significant differences in TUT_{sum1-5} between BEG and ADV were found only for the SLO tempo (Table 3). Contrary to TUT_{sum1-5} values, no significant difference was demonstrated for REP_{sum1-5} between the BEG and ADV groups (Table. 4). These findings are consistent with the guidelines discussed in a study by Wilk et al. [12], thus confirming the usefulness of determination of exercise volume by means of TUT rather than REP only. Duration of a single repetition i.e. total duration of concentric and eccentric cadences and duration of isometric rest pauses between phases is determined by the speed at which the repetition is performed [6,8]. TUT determines the volume of work performed more accurately than REP, which is especially noticeable in case of slower movement tempos. In the present study, the duration of one repetition with the SLO tempo was 10 seconds, whereas the point of maximal muscle fatigue (MMF) could occur at any moment of the exercise, which could be determined only by TUT rather than REP. In case of the analysis of the volume based on REP values, failure to perform a repetition, even if 8–9 second work was performed within the 10-second movement tempo led to the lack of recording the repetition as a measure of exercise volume, which substantially limits the reliability of such measurements. In case of TUT, the number of the seconds of work is recorded for the instant of actual exhaustion, regardless of the phase and moment of performing the movement. The legitimacy of the evaluation of exercise volume based on the duration of the TUT_{set} or TUT_{sum} as a value of the total muscle contraction for the exercise and entire training session, respectively, concerns any value of tempo. However, the slower the movement tempo and cadence, the higher differences between TUT and REP variables. A significant difference was demonstrated in values of TUT_{sum1-5} between BEG and ADV groups. Interestingly, the ADV group obtained a lower value of TUT_{sum1-5} 178s (±33) compared to the BEG group, TUT_{sum1-5} 203.8s (±33.9) (Tab. 3). Higher TUT values in the BEG group are likely to be linked to the ratio of FT/ST muscle fibres involved in the exercise. Adaptations resulting from strength training lead to transformation of muscle fibres [15,16,21–23]. The most intensively growing fibres are of type II, with high number of myofibrils, which are characterized not only by greater contraction force but also lower susceptibility to fatigue [16]. Type I muscle fibres are characterized by aerobic metabolism, low contraction force and high resistance to fatigue. These fibres to not react well to resistance training, and show limited hypertrophy. Advanced strength trained subjects are characterized by greater percentage of type IIa and IIb muscle fibres compared to beginners. A higher percentage of type IIa and type IIb fibres during resistance training in advanced athlete, especially in SLO tempo, impacts muscle contraction recorded during exercise, which is related to the level of metabolic stress leading to MMF. Combined with changed concentrations of hydrogen ions and deficiency of adenosine triphosphate (ATP), the increased concentration of metabolic products is directly related to the achieved TUT. This was especially noticeable for SLO tempo in the ADV group, which is consistent with the findings published by Hatifield et al. [5], who showed that slow movement tempo leads to higher muscle fatigue, analysed both, based on the level of muscle power and self-reported exhaustion of study participants. In case of the SLO tempo, significant difference in TUT_{sum1-5} was caused in particular by the differences in TUT_{set1} and TUT_{set2} (Figure 1). Greater value of TUT_{set1} TUT_{set2} in the BEG group compared to ADV can be linked, similar to TUT_{sum1-5} to the ratio of muscle fibre types, with the dominance of IIa and IIb fibres in the ADV compared to the BEG group. The results, with particular focus on differences in TUT_{set1}, TUT_{set2} and TUT_{sum1-5} for SLO tempo, are consistent with previous reports which have indicated that slower movement tempo impacts on training volume and intensity [5,11–14]. TUT_{set3-5} did not show significant differences between the BEG and ADV groups, which is likely to be related to the fact that metabolic exhaustion was observed and post exercise metabolites were accumulated in both the BEG and in ADV groups in TUT_{set1} and TUT_{set2}, thus limiting exercise capacity in the next sets of the experiment. Exhaustion at this level of exercise can be assumed to be equivalent in the BEG and ADV groups. In case of REG tempo, significant changes in TUT were found only in TUT_{set5}, where BEG group was able to perform the bench press with 2/0/2/0 tempo for a significantly longer duration compared to the ADV group. The significance of the TUT_{set5} difference did not impact on TUT_{sum1-5}. The study did not find significant differences in TUT_{sum1-5} for the REG and MED tempos, which can indicate that only the exercise using extremely slow tempo differentiate the value of exercise volume depending on the level of experience in resistance training.

CONCLUSIONS

Significant differences in TUT_{sum1-5} in the case of SLO tempo may suggest that the slower the movement tempo or cadence of particular movement phases, the less pronounced the differences resulting from the level of experience in resistance training. In case of REP, the tests did not show significant differences in REP_{sum1-5} in any of the analysed movement tempos. This is consistent with the suggestion by Wilk et al. [12] who indicated that the value of TUT is a more accurate determinant of exercise volume compared to REP. Significant differences in TUT_{sum1-5} and TUT_{set} both for the SLO and REG tempos confirm that both movement tempo [12] and level of experience in strength training influence exercise volume.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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PRACA NR 2

„Analysis of power output and bar velocity during various techniques of the bench press among women”

W drugim badaniu analizie poddano wpływ wyciskania sztangi leżąc z szerokim (Wide Grip Bench Press – WGBP) i wąskim chwytem sztangi (Close Grip Bench Press – CGBP) na poziom mocy mięśniowej i prędkości sztangi w ruchu koncentrycznym przy zmiennym czasie trwania fazy ekscentrycznej (6/0/X/0 vs. 2/0/X/0). Ocena wpływu zmiany czasu trwania fazy ekscentrycznej oraz rodzaj chwytu sztangi stanowiły główny problem badawczy pracy *„Analysis of power output and bar velocity during various techniques of the bench press among women”* opublikowanej w czasopiśmie *„Journal of Human Sport and Exercise”.* w badaniu wzięło udział 20 kobiet w wieku 26.6 ± 2.6 lat, masie ciała 54.4 ± 7.5 kg, doświadczeniem w treningu oporowym 2.5 ± 0.94 lat, 1-RM CGBP: 55.2 ± 7.5 kg, 1-RM WGBP: 52.9 ± 6.5 kg. Procedura badawcza obejmowała cztery protokoły testowe (WGBP 2/0/X/0, WGBP 6/0/X/0, CGBP 2/0/X/0, CGBP 6/0/X/0). WGBP obejmował dystans między dłońmi 81cm, który stanowił ponad 200% odległości najbardziej wysuniętych na zewnątrz punktów „acromion” - wyrostków szczytu barkowego (Biacriomial Distance - BAD) dla każdej uczestniczki badania, natomiast CGBP charakteryzował odległość 95% BAD. Uczestniczki badania wykonywały jedną serię (trzy powtórzenia) wyciskania sztangi leżąc, stosując obciążenie zewnętrzne o wartości 70% 1-RM. Czas trwania fazy ekscentrycznej wynosił 2s lub 6s, natomiast fazę koncentryczną wykonywano z maksymalną prędkością („X”). Szczegółowa analiza dotyczyła zmian prędkości sztangi oraz mocy mięśniowej w ruchu koncentrycznym, przy zastosowaniu zmiennego czasu trwania fazy ekscentrycznej i zmiennej szerokości chwytu sztangi. do oceny prędkości sztangi oraz generowanej mocy mięśniowej wykorzystano system „Tendo Power Analyzer” (Tendo Sport Machines, Trencin, Slovakia). Hipoteza badawcza zakładała, że zarówno zmiana czasu trwania fazy ekscentrycznej, jak i zmiana szerokości chwytu sztangi znacząco wpływa na poziom generowanej mocy mięśniowej i prędkość sztangi.

Wyniki badań wykazały, że zmiana czasu trwania fazy ekscentrycznej ruchu istotnie wpływa na prędkość sztangi i moc mięśniową podczas wyciskania sztangi leżąc.

Poziom generowanej mocy mięśniowej i prędkość sztangi były istotnie wyższe przy zastosowaniu krótszego czasu trwania fazy ekscentrycznej (2/0/X/0), w porównaniu z dłuższym (6/0/X/0) czasem trwania tej fazy. Zaobserwowane istotne różnice między analizowanymi zmiennymi dotyczyły średnich wartości prędkości sztangi pomiędzy WGBP 6/0/X/0 i WGBP 2/0/X/0 ($p < 0.01$) i szczytowej prędkości sztangi ($p < 0.01$), pomiędzy WGBP 6/0/X/0 i CGBP 2/0/X/0 dla szczytowej mocy mięśniowej ($p < 0.05$), średniej prędkości sztangi ($p < 0.01$) i szczytowej prędkości sztangi ($p < 0.05$) oraz między CGBP 6/0/X/0 i CGBP 2/0/X/0 dla średniej prędkości sztangi ($p < 0.05$). Ponadto nie stwierdzono istotnych różnic między szerokim, a wąskim chwytem sztangi w wartości mocy mięśniowej i prędkości sztangi podczas wyciskania sztangi leżąc wykorzystując stały, kontrolowany czas trwania fazy ekscentrycznej ruchu.

Wyniki niniejszego badania są zgodne z ustaleniami Wilka i wsp. (2019a), którzy analizowali wpływ czasu trwania fazy ekscentrycznej na poziom generowanej mocy mięśniowej w fazie koncentrycznej w grupie mężczyzn. Autorzy wykazali, że 6-cio sekundowy czas trwania fazy ekscentrycznej miał niekorzystny wpływ na wartość mocy mięśniowej oraz prędkość sztangi w fazie koncentrycznej zarówno w wartościach średnich, jak i maksymalnych, w przeciwieństwie do 2s fazy ekscentrycznej. Wyniki przeprowadzonych badań oraz Wilka i wsp. (2019a) wskazują, że podczas treningu oporowego, którego celem jest kształtowanie mocy mięśniowej, należy zwrócić szczególną uwagę nie tylko na pracę wykonywaną podczas fazy koncentrycznej, ale także na czas trwania ekscentrycznej fazy ruchu. z przeprowadzonych badań wynika, że rodzaj chwytu sztangi nie był czynnikiem istotnie wpływającym na poziom generowanej mocy mięśniowej i prędkości sztangi w grupie kobiet, co jest sprzeczne ze wcześniejszymi doniesieniami (Lockie i wsp., 2017; Saeterbakken i wsp., 2017). Lockie i wsp. (2017) wykazali, że wykorzystanie CGBP (95% BAD) skutkowało niższą wartością maksymalnego obciążenia zewnętrznego w teście 1-RM, w porównaniu do tradycyjnego chwytu sztangi (TBP = 165-200% BAD), a preferowany chwyt sztangi wśród osób badanych wynosił ok. 175% BAD. Jednak szczytowy poziom generowanej mocy mięśniowej oraz prędkości sztangi odnotowano podczas CGBP, w przeciwieństwie do TBP (Lockie i wsp., 2018). Należy zaznaczyć, że prezentowany projekt badawczy dotyczy wyłącznie grupy kobiet, w przeciwieństwie do badań Lockiego i wsp. (2017), w których uwzględniono grupę mieszaną (21 mężczyzn i 6 kobiet), co mogło mieć znaczący wpływ na wyniki badań.

Głównym czynnikiem wpływającym na różnice prędkości sztangi i generowanej mocy mięśniowej był czas trwania fazy ekscentrycznej ruchu. Wcześniejsze badania wykazały obniżenie wartości generowanej mocy mięśniowej i prędkości sztangi w ruchu koncentrycznym (Wilk i wsp., 2019a), gdy wykorzystywano wolniejszą fazę ekscentryczną (6/0/X/0), co jest zgodne z prezentowanymi badaniami. Podczas wolnego tempa powtórzenia długość fazy ekscentrycznej trwała trzykrotnie dłużej, w przeciwieństwie do krótkiego czasu trwania powtórzenia (6s vs. 2s). Dłuższy czas trwania wysiłku może prowadzić do większego zmęczenia mięśniowego, a w konsekwencji do osiągania gorszych wyników mocy mięśniowej i prędkości sztangi. Trzykrotnie dłuższy czas trwania powtórzenia, w porównaniu z krótkim czasem trwania powtórzenia wskazuje na wyższą wartość TUT (Wilk i wsp. 2018b, 2019a), a tym samym na wyższą objętość wysiłku. Pomimo tej samej liczby powtórzeń, czas trwania jednego powtórzenia, czyli tempo powtórzenia znacząco się różnił. Fakt, że długość trwania fazy ekscentrycznej wpływa na wartość TUT, REP, moc mięśniową oraz prędkość sztangi sugeruje, że czas trwania powtórzenia w treningu oporowym jest zmienną, którą należy brać pod uwagę podczas programowania i realizowania ćwiczeń siłowych. Wyniki badań były podstawą do realizacji kolejnych projektów badawczych, w których ocenie poddano wpływ czasu trwania powtórzenia na wartość wyniku uzyskanego w teście 1-RM.

Original Article

Analysis of power output and bar velocity during various techniques of the bench press among women

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ABSTRACT

Background: The aim of the study was to determine the effect of the wide grip bench press (WGBP) and the close grip bench press (CGBP) on power output and bar velocity changes using a variable tempo of movement (6/0/X/0 vs. 2/0/X/0) in a group of female athletes. Objective: Twenty females were enrolled in the study (age 26.6±2.6, body mass 54.4±7.2 kg, RT experience 2.5±0.94 years; CGBP 1RM 55.2±7.5 kg; WGBP 1RM 52.9±6.5 kg). Method: Participants performed two sets of three repetitions of the bench press (BP) at 70%1RM with different grip widths (WGBP or CGBP) and different tempos of movement (2/0/X/0 or 6/0/X/0). During each test the following variables were registered: mean power (MP), peak power (PP), mean velocity (MV), and peak velocity (PV). Results: The repeated measures ANOVA showed significant differences between analysed variables for MV, PV and PP. The post hoc Tukey showed significant differences between WGBPSLOW and WGBPFAST for MV ($p<0.01$) and PV ($p<0.01$), significant differences between WGBPSLOW and CGBPFAST for PP ($p<0.05$), MV ($p<0.01$) and PV ($p<0.05$). Finally, the study showed significant differences between CGBPSLOW and CGBPFAST for MV ($p<0.05$). Conclusion: The present research showed that the movement tempo significantly influenced the level of power output and bar velocity during the BP. Furthermore, it was demonstrated that the type of grip width during the BP is not a factor significantly affecting the level of power output and bar velocity. **Keywords:** Resistance exercise; Movement tempo; Close-grip; Wide-grip; Strength.

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INTRODUCTION

The bench press (BP) is one of the upper-body exercises most frequently used in resistance training (Baker et al., 2001; Stock et al., 2010; Krzysztofik et al., 2019; Wilk et al., 2019c). The BP is usually performed with an individually adjusted grip width, which was defined by Young et al. (2015) as "the strongest position" termed also a traditional bench press (TBP). However, athletes also often use the wide-grip bench press (WGBP) and the close-grip bench press (CGBP). The WGBP is described as a bench press with a grip width of 200% or more of the biacromial distance (BAD), while the CGBP is defined as a grip width of 95% BAD (Wagner et al. 1992; Barnett et al., 1995; Lockie et al., 2017a; 2017b; Wilk et al., 2019a).

The ability to generate high levels of strength and power output is one of the most significant factors that determines performance in numerous sport disciplines (Cronin and Hansen, 2005; Argus et al., 2014; Gołaś et al., 2017). Previous studies have shown that differences in the level of maximum strength and power output may depend on the width grip used during the BP (Saeterbakken et al., 2017; Lockie et al., 2018). Saeterbakken et al. (2017) showed that the WGBP (165 - 200% BAD) allowed higher maximum external loads compared to the CGBP. The values of 6-RM were 11.1% greater using the WGBP compared to the CGBP. Lockie et al. (2018) showed that peak power output during the WGBP occurred at 50% of 1RM, while for the CGBP at 30% of 1RM. Furthermore, the CGBP resulted in a lower maximal external load one repetition maximum test (1RM), higher peak power output and velocity as well as lower mean force compared to the WGBP (Lockie et al., 2018). The level of power output during the BP depends not only on the width grip used, but also on gender (Bishop et al., 1987; Miller et al., 1993; Amasay et al., 2016) and the level of experience in resistance training (Miller et al., 2019). Miller et al. (2019) indicated that trained females produced peak power output at 50%1RM, while untrained women at 60-70%1RM during the TBP.

What is important is that the level of power output and bar velocity in the BP depend also on the duration of the eccentric (ECC) contraction. A study by Wilk et al. (2019b) showed that a slower ECC cadence (6 s) during the BP had an adverse effect on power output and velocity during the concentric (CON) phase compared to the BP performed with a faster ECC cadence (2 s). Significant decreases were observed for both peak and mean power output as well as for bar velocity Wilk et al., (2019b). However, in that study Wilk et al. (2019b) the width grip was determined not on the basis % BAD, but on the basis of the width of the handle which amounted to 81 cm. Although previous studies have demonstrated that significant differences in power output depend on the grip width used in the BP (Lockie et al., 2017a; 2017b) none of them referred to different movement tempos during the exercise.

The movement tempo is usually described using a sequence of digits (e.g. 2/0/X/0), where each digit determines the duration (s) of a particular phase of the movement. Since there is no standardized method of assigning these digits within the scientific literature, in this paper we adopted a unified description of the movement tempo as follows: eccentric / isometric / concentric / isometric. Previous research has shown that changes in the movement tempo during resistance exercise have an impact on the volume and intensity of effort, and in turn, the resultant adaptive changes in maximum strength, power and hypertrophy (Keeler et al., 2001; Hunter et al., 2003; Gołaś et al., 2017; Wilk et al., 2018a; 2018b).

Despite the fact that training with a controlled movement tempo has become more popular in sports practice as well as in scientific research, there are no available data concerning the influence of the grip width and movement tempos on level of power output and bar velocity changes during the BP. Therefore, the aim of the study was to determine the effects of different grip widths in the BP (WGBP vs. CGBP) performed with different movement tempos (6/0/X/0 vs. 2/0/X/0) on power output and bar velocity in a group of female athletes.

MATERIAL AND METHODS

Participants

Twenty (20) healthy female experienced in resistance training (2.5 ± 0.94 yrs.) volunteered for the study after completing an ethical consent form (age = 26.6 ± 2.6 years; body mass = 54.4 ± 7.2 kg; CGBP 1RM = 55.2 ± 7.5 kg; WGBP 1RM = 52.9 ± 6.5 kg; mean ± SD). All study participants were over 18 years of age and were expected to be able to perform a bench press with the load of at least 100% of their body mass. Participants were allowed to withdraw from the experiment at any moment and were free of any pathologies or injuries. The study protocol was approved by the Bioethics Committee for Scientific Research at the Academy of Physical Education in Katowice, Poland, according to the ethical standards of the latest version of the Declaration of Helsinki, 2013.

Procedures

The experiment was performed following a randomized crossover design, where each participant performed a familiarization session with a 1RM test and four different testing protocols 3-4 days apart. Participants performed the WGBP with a 2/0/X/0 ($WGBP_{FAST}$), and a 6/0/X/0 ($WGBP_{SLOW}$) tempo. They also followed the same exercise procedures with the CGBP using a 2/0/X/0 ($CGBP_{FAST}$) and a 6/0/X/0 ($CGBP_{SLOW}$) tempo. During each experimental session, participants performed one set of 3 repetitions at 70%1RM. The following variables were registered: peak power (PP), mean power (MP), peak velocity (PV) and mean velocity (MV). Participants were required to refrain from resistance training 48 hours prior to each experimental session, were familiarized with the protocol as well as informed of the benefits and potential risks of the study and provided their written consent for participation in the study.

1RM WGBP and CGBP Strength Testing

All testing was performed at the Strength and Power Laboratory of the Academy of Physical Education in Katowice, Poland. Participants arrived at the laboratory between 9:00 and 11:00 a.m. and cycled on an ergometer for 5 minutes, which was followed by a general upper body warm-up and 15 push-ups. Next, participants performed 15, 10, and 5 BP repetitions using 20%, 50%, and 70% of their estimated 1RM, respectively. The 1RM test with the WGBP was performed first. The grip width adopted for the WGBP was 200% BAD (Wagner et al., 1992; Saeterbakken et al., 2017). The grip width was marked on the barbell with athletic tape, and a pronated grip was used. Participants placed their hands on the bar at the same position for each set. Participants executed single repetitions using a volitional cadence with a 3-min rest interval between successive trials. The load for each subsequent attempt was increased by 1.25 - 5 kg, and the process was repeated until failure. No more than five attempts were allowed before the 1RM was determined for each participant. After a 10 min recovery period, participants completed the 1RM test in the CGBP (Lockie et al., 2017a; 2017b). The body position and constraints that determined a successful lift were the same as those for the WGBP, except for the different grip width. The grip width adopted for the CGBP was 95% BAD (Cronin, 2001; Cronin & Owen, 2004; Cronin & Hansen, 2005). Following the established procedures, the warm-up for the second 1RM test began by completing 3–5 repetitions at 85% of the participants' estimated 1RM, and then one repetition with 90%1RM. Afterwards, participants attempted their first 1RM lift following a 3-min recovery period, and this process continued until 1RM was reached. For both the WGBP and the CGBP, absolute strength was taken as the maximum load lifted. An IPF Eleiko bar and weight plates (Eleiko, Sport AB Sweden) were used for both the WGBP and the CGBP.

Experimental sessions
The general and specific warm-up before the experimental sessions was identical to that used during the familiarization session. After the warm up, participants performed one set of the bench press with a particular grip width (WGBP or CGBP) and a specified tempo (2/0/X/0 or 6/0/X/0) with 70%1RM following a metronome guided movement cadence in the eccentric phase (Korg MA-30, Korg, Melville, New York, USA). The concentric phase was performed at the maximal tempo of movement (X). Each experimental set included 3 repetitions. All repetitions were performed without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases, and without raising the lower back off the bench. The intervals between experimental sessions were 3-4 days. All familiarization and experimental sessions were recorded by means of a Sony camera (FDR191 AX53). All participants completed the described testing protocol.

Statistical analysis
The statistical analyses were performed using STATISTICA software (StatSoft, Inc., Tulsa OK Oklahoma, USA, 2018 - version 12). Values of power output and velocity were expressed as mean ± SD. Before using the parametric test, the assumption of normality was verified using the Kolmogorov-Smirnov test. The repeated measures ANOVA was used to show differences between collected variables. When significant main effects occurred, post-hoc comparisons were conducted using the Tukey's test.

RESULTS

The repeated measures ANOVA showed significant differences between analysed variables for MV, PV and PP (Table 1). The post hoc Turkey showed significant differences between $WGBP_{SLOW}$ and $WGBP_{FAST}$ for MV ($p<0.01$) and PV ($p<0.01$), significant differences between $WGBP_{SLOW}$ and $CGBP_{FAST}$ for PP ($p<0.05$), MV ($p<0.01$) and PV ($p<0.05$) (Table 2). Finally, the study showed significant differences between $CGBP_{SLOW}$ and $CGBP_{FAST}$ for MV ($p<0.05$) (Table 2).

Table 1. Power output and bar velocity during the various techniques of the bench press.

	$WGBP_{SLOW}$	$WGBP_{FAST}$	$CGBP_{SLOW}$	$CGBP_{FAST}$	*P*
MP [W]	121 ± 35	134 ± 24	131 ± 35	141 ± 46	0.92
PP [W]	186 ± 67	196 ± 40	203 ± 60	219 ± 65	0.05*
MV [m/s]	0.39 ± 0.07	0.48 ± 0.05	0.46 ± 0.08	0.51 ± 0.05	0.05*
PV [m/s]	0.61 ± 0.11	0.72 ± 0.08	0.69 ± 0.17	0.70 ± 0.07	0.01*

*All data are presented as mean ± standard deviation; *statistically significant differences p<0.05*

Table 2. Differences in power output and bar velocity during the various techniques of the bench press.

Bench press techniques	MP [w]	PP [w]	MV [m/s]	PV [m/s]
	P	*p*	*p*	*p*
$WGBP_{SLOW}$ vs. $WGBP_{FAST}$	0.88	0.97	0.01*	0.01*
$CGBP_{SLOW}$ vs. $WGBP_{FAST}$	0.96	0.98	0.86	0.89
$WGBP_{FAST}$ vs. $CGBP_{FAST}$	0.34	0.75	0.60	0.98
$WGBP_{SLOW}$ vs. $CGBP_{SLOW}$	0.63	0.88	0.28	0.41
$WGBP_{SLOW}$ vs. $CGBP_{FAST}$	0.75	0.05*	0.01*	0.05*
$CGBP_{SLOW}$ vs. $CGBP_{FAST}$	0.61	0.90	0.05*	0.98

*All data are presented as mean ± standard deviation; *statistically significant differences p<0.05*

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What is important, the present study is the first which in addition to different movement tempos has also considered different grip widths during the BP. Previous research has confirmed that significant differences in the level of power output and velocity of movement depend on the grip width (Lockie et al., 2017a; 2017b). Studies by Lockie et al. (2017a; 2017b) and van den Tillaar (2012) showed that higher values of power output and bar velocity were achieved in the CGBP compared to the TBP, which was not confirmed in our study. Importantly, the present study showed that power output did not depend on the grip width which contradicts the results of Lockie et al. (2017a; 2017b; 2018), who showed that peak power output, peak velocity, and mean velocity were greater for the CGBP compared to the TBP.

CONCLUSION

The present research showed that the type of grip width during the BP was not a factor significantly affecting the level of power output and bar velocity generated in a group of female athletes. Furthermore, it was demonstrated that the movement tempo significantly influenced the efficiency of resistance exercise. In order to develop a high level of power output during CON contractions, one should strive for maximally dynamic performance of the ECC phase. Therefore, the tempo of movement represents a component of resistance training, which should be controlled and taken into consideration during planning and execution of resistance training programs.

AUTHOR CONTRIBUTIONS

Study concept and design: Mariola Gepfert and Aleksandra Filip; Acquisition of data: Mariola Gepfert, Maciej Kostrzewa and Paulina Królikowska; Analysis and interpretation of data: Aleksandra Filip, Grzegorz Hajduk and Robert Trybulski; Writing—original draft: Mariola Gepfert, Aleksandra Filip and Paulina Królikowska; Writing—review and editing: Aleksandra Filip, Mariola Gepfert and Michał Krzysztofik; Supervision: Michał Krzysztofik.

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The authors state that there are no conflicts of interest.

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DISCUSSION

The main finding of the study was that the movement tempo had a significant effect on power output and bar velocity during the bench press exercise. Significant differences were observed between $WGBP_{SLOW}$ and $WGBP_{FAST}$ for MV, PV, between $WGBP_{SLOW}$ and $CGBP_{FAST}$ for PP, MV and MV, as well as between $CGBP_{SLOW}$ and $CGBP_{FAST}$ for MV. Results of the aforementioned comparisons showed that the level of power output and velocity of movement was significantly higher at the fast tempo of movement compared to the slow tempo of movement. Furthermore, no significant differences were found between wide of grip used during the BP with a constant movement tempo.

To date, several studies have confirmed the effect of the movement tempo on the number of repetitions performed, time under tension and exercise volume (Sakamoto & Sinclair, 2006; Wilk et al., 2018a; 2018b; 2018c; 2019a), but the present study is the first one which analysed both the movement tempo and the width grip. Results of the present study are consistent with previous findings of Wilk et al. (2019), who showed increase level of power output and bar velocity during the BP with fast movement tempo compared to slower one. However, compared to the results obtained by Wilk et al. (2019b), presented study do not showed significant changes in MP for all used techniques. Such differences may result from the fact that in presented study subjects consisted of female athletes, while in the study of Wilk et al. (2019b) study participants were males. Gender differences have a significant effect on skeletal muscle morphology and function (Haizlip et al., 2015), as well as on muscle substrate utilization and neuromuscular activation (Hicks et al., 2001). Previous research suggests that the greater strength of men compared to woman is primarily due to greater muscle fibres levels (Miller et al., 1993) and a higher proportion of type I fibres compared to type II (Staron et al., 2000; Roepstroff et al., 2006; Welle et al., 2006). Furthermore, men produce significantly greater strength as well as absolute and relative peak and mean power during the bench press compared to women (Lovell et al., 2011). In the bench press throw, women achieve peak power output at 30-50%, whereas men at 30% (Thomas et al., 2007). Moreover, another study indicated that men achieved higher mean velocity for light loads, whereas women reported higher mean velocity for heavy loads during the BP on a Smith machine (Torrejón et al., 2018). These data suggest that various training strategies should be used in training for men and women to develop power output.

The main factor influencing differences in power output and bar velocity between the applied tempos of movement was the duration of the ECC phase of movement. In the present study, the duration of the ECC phase in the slow tempo of movement was three times longer than for the fast tempo of movement (ECC_{SLOW} - 6s; ECC_{FAST} - 2s). Therefore, longer duration of effort can lead to greater muscle exhaustion and consequently, premature exercise fatigue. Duration of effort also referred to as time under tension, can be an indicator of exercise volume regardless of the number of repetitions performed (Wilk et al., 2018a; 2018b). Three times longer duration of effort during the slow compared to the fast tempo of movement indicates higher exercise volume which is linked to greater energy expenditure during the longer ECC contraction and greater fatigue, what significantly decreases the value of power output and bar velocity during the BP with the slow compared to the fast movement tempo. The higher value of power output and bar velocity during the faster tempo can be related not only to the duration of effort in the ECC phase of movement, but also to a more effective use of elastic energy generated during the faster ECC contraction, which is released during the CON phase of the movement (Newton et al., 1997; Cronin et al., 2001; Cronin & Owen, 2004;). Previous research has shown decreases in power output and velocity when the slower ECC phase was used, what was partially linked to less efficient utilization of the stretch-shortening cycle (Wilk et al., 2019b). Similar relationships were observed when analysing the effects of post-activation potentiation, which was less effective when slow ECC phases were used (Wilk et al., 2019c).

PRACA NR 3

„Impact of Duration of Eccentric Movement in the One-Repetition Maximum Test Result in the Bench Press among Women"

Kolejne badanie dotyczyło oceny wpływu czasu trwania ekscentrycznej fazy ruchu na wynik testu 1-RM podczas wyciskania sztangi leżąc zawarte w pracy: *„Impact of Duration of Eccentric Movement in the One-Repetition Maximum Test Result in the Bench Press among Women"* opublikowane w czasopiśmie *„Journal of Sports Science and Medicine"*. Głównym celem badania było ustalenie czy długość trwania ekscentrycznej fazy ruchu wpływa na wynik testu 1-RM podczas wyciskania sztangi leżąc. w badaniu wzięło udział 21 kobiet (23.4 ± 2.2 lat; masa ciała: 52.3 ± 6.7 kg), z minimalnym rocznym doświadczeniem w treningu oporowym (2.3 ± 1.47 lat). Procedura badawcza została podzielona na trzy protokoły, w której uczestniczki wykonywały test 1-RM podczas wyciskania sztangi leżąc z określonym czasem trwania fazy ekscentrycznej ruchu (2/0/X/0; 4/0/X/0; 6/0/X/0), natomiast fazę koncentryczną wykonywano z maksymalną prędkością („X"). Przerwa między seriami wynosiła 5 minut, natomiast wszystkie wartości 1-RM uzyskano w czterech próbach. Hipoteza badawcza zakładała, że czas trwania ekscentrycznej fazy ruchu wpływa na wynik testu 1-RM w wyciskaniu sztangi leżąc wśród kobiet.

Głównym wnioskiem przeprowadzonych badań był fakt, że dłuższy czas trwania ekscentrycznej fazy ruchu skutkował obniżeniem wartości maksymalnego obciążenia zewnętrznego w teście 1-RM, co potwierdziło hipotezę badawczą. Wyniki testu 1-RM, w którym zastosowano długą fazę ekscentryczną (6/0/X/0) był istotnie niższy, w porównaniu ze średnią (4/0/X/0; $p < 0.01$) i krótką (2/0/X/0; $p < 0.01$) długością trwania fazy ekscentrycznej ruchu. Ponadto wyniki testu 1-RM w tempie 4/0/X/0 były również istotnie niższe, w porównaniu do tempa 2/0/X/0 ($p < 0.01$).

Wyniki przeprowadzonych badań są zgodne z badaniami Headley i wsp. (2011), w których uczestnicy osiągnęli o 3.7% wyższe wyniki podczas testu 1-RM stosując czas trwania powtórzenia 2/0/2/0, w porównaniu z tempem powtórzenia 4/0/2/0. Można więc założyć, że dodatkowe wydłużenie fazy ekscentrycznej, np. do 10s, jak w badaniu Hatfielda i wsp. (2006) spowodowałoby dodatkowy spadek wartości wyników testu 1-

RM. Schoenfeld i wsp. (2015) zasugerowali, że dłuższy czas trwania wysiłku, szczególnie w fazie ekscentrycznej ruchu, może prowadzić do większego zmęczenia mięśniowego, a w konsekwencji do spadku maksymalnego obciążenia zewnętrznego w teście 1-RM. w przeciwieństwie do krótkiego czasu trwania fazy ekscentrycznej ruchu (2/0/X/0), podczas wykonania powtórzenia trwającego 6s w fazie ekscentrycznej ruchu wskazuje na dłuższy TUT, które znacząco zmniejsza wartość obciążenia zewnętrznego osiągniętego w teście 1-RM (Suchomel i wsp., 2019a, 2019b). Zatem wyższy wynik testu 1-RM podczas krótkiej fazy ekscentrycznej ruchu (2/0/X/0), w porównaniu do długiej fazy ekscentrycznej ruchu, jest bezpośrednio związany z wartością TUT. Pomimo znaczących różnic w wynikach testu 1-RM między czasem ruchu fazy ekscentrycznej: 2/0/X/0, 4/0/X/0, 6/0/X/0, rzeczywista różnica (kg) była raczej niewielka i sięgała od 0 do 2.5 kg między 4/0/X/0, a 6/0/X/0 oraz od 2.5 do 5 kg między 2/0/X/0 i 6/0/X/0. O ile taką różnicę w wynikach testu 1-RM można uznać za niewielką w warunkach rzeczywistych, może mieć ona ogromne znaczenie w treningu oporowym oraz w rywalizacji sportowej dyscyplin, w których sukces zależy od siły maksymalnej (Kraemer i Ratamess, 2004; Suchomel i wsp., 2016). Nawet jeśli dłuższy czas trwania fazy ekscentrycznej ruchu powoduje nieznaczny spadek wyników testu 1-RM, korzyści wynikające ze zwiększonego TUT mogą oddziaływać na bezpośrednie i długofalowe reakcje adaptacyjne w treningu oporowym. Bird i wsp. (2005) oraz Burd i wsp. (2012) zasugerowali, że dłuższy TUT może być korzystny w rozwoju hipertrofii mięśniowej, zwłaszcza przy wolniejszej ekscentrycznej fazie ruchu (Schoenfeld, 2010). Ponadto wyższa wartość TUT może prowadzić do większego uszkodzenia mięśniowego (Schoenfeld, 2010) stymulując rozwój hipertrofii mięśniowej (Burd i wsp., 2012).

Wyniki uzyskane w badaniu mają istotne znaczenie w ocenie poziomu siły mięśniowej. Test 1-RM ma szerokie zastosowanie w ocenie siły mięśniowej w warunkach nielaboratoryjnych (Levinger i wsp., 2009). Metoda wyznaczania 1-RM polega na zastosowaniu maksymalnego obciążenia zewnętrznego pojedynczego skurczu mięśnia (ekscentrycznego i koncentrycznego) (Fry, 2004). Dotychczasowe badania naukowe nie uwzględniały w procedurze testowania czasu trwania fazy ekscentrycznej ruchu, co skutkowało niewiarygodnym pomiarem. Doniesienia naukowe opisujące wpływ tempa powtórzenia na bezpośrednie i długofalowe zmiany adaptacyjne w treningu oporowym wykorzystują określone wartości % 1-RM (campos i wsp., 2002; Mike i wsp., 2017; Wilk i wsp., 2018b), zatem wyniki niniejszego badania mają znaczenie nie tylko ze względu na wynik testu 1-RM, ale także na procedurę badań naukowych. Jeśli wartości % 1-RM zostaną obliczone na podstawie testu 1-RM z wolicjonalnym czasem ruchu, wartości te nie będą wiarygodne podczas treningu ze zmiennym, a szczególnie z wolnym czasem trwania powtórzenia. Dlatego procedura testu 1-RM powinna zawierać informacje o czasie trwania poszczególnej fazy ruchu wykorzystanej podczas próby. Ponadto, gdy w protokołach testowych wykorzystywane są różne długości faz ruchu, test 1-RM powinien być wykonywany niezależnie dla każdego tempa powtórzenia.

Wyniki badań skłoniły do realizacji kolejnego protokołu badawczego, w którym ocenie poddano wpływ czasu trwania powtórzenia w ćwiczeniach oporowych na powysiłkowy poziom reakcji endokrynnych.

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Resarch article

Impact of Duration of Eccentric Movement in the One-Repetition Maximum Test Result in the Bench Press among Women

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Abstract
Scientific studies related to resistance training have considered many variables; however, the tempo of movement of particular repetitions is often neglected or not reported in resistance training practice and research. The aim of the study was to determine the effect of different duration of the eccentric (ECC) phase of movement on one-repetition maximum test (1RM) results during the bench press exercise (BP). Twenty-one strength trained females (age = 23.4 ± 2.2 years, body mass = 52.3 ± 6.7 kg), with a minimum one year of strength training experience took part in the study. The experiment was conducted following a randomized crossover design, where each participant completed the 1RM test in the BP with three different duration times of the ECC movement: 2/0/X, 4/0/X, 6/0/X. Concentric (CON) movement was performed with maximal velocity (X). The ANOVA with repeated measures were used to compare the differences between the analyzed variables. The results of the study indicated the maximal load in the 1RM test was significantly higher during the BP with the 2/0/X tempo compared to 6/0/X ($p < 0.01$) and 4/0/X tempos ($p < 0.01$). Therefore, the results indicated that the longer the duration of the ECC phase of movement, the greater the decrease in the result of the 1RM test. The 1RM test procedure should include information about the movement tempo used during the test protocol.

Key words: Performance, resistance, strength; duration of repetition.

Introduction

Maximum strength is the maximum capability of a muscle or a muscle group to generate tension. It is often measured by the one repetition maximum test (1RM) (Seo et al., 2012). The 1RM test is defined as the maximal load that can be lifted once with a correct technique and over a specific range of motion. The 1RM test is relatively simple and requires inexpensive non-laboratory equipment (Kraemer et al., 2006). The 1RM test is considered the gold standard for assessing muscle strength under non-laboratory conditions (Levinger et al., 2009). Due to the wide use of 1RM tests, it is important that this test is a reliable measurement, however, it has not been established what effect different tempos of movement have on the results of the 1RM test as yet.

Training at a specific movement tempo is a concept in resistance training, where the duration of particular phases of movement is strictly controlled and manipulated (Wilk et al., 2018a). Since there is no standardized method within the scientific literature, in this paper we applied a unified description of the movement tempo using the following terms and three-digit combination: eccentric / isometric / concentric (e.g. 2/0/X), where each digit determined the duration [s] of a particular phase of the movement. “X” represented the maximum possible movement tempo during the concentric (CON) phase.

Previous research has shown that changes in movement tempo during resistance exercise have a significant impact on the number of performed repetitions, time under tension as well exercise intensity, and as a consequence influence adaptive changes related to strength, power and muscular hypertrophy (Hunter et al., 2003; Keeler et al., 2001; Wilk et al., 2018a; 2019). However, despite the fact that training with a controlled movement tempo influences acute responses (endocrine, metabolic, fatigue) and chronic changes (muscular strength and hypertrophy) following resistance exercise, only one study has examined the impact of different movement tempos on the maximal load lifted during 1RM testing (Headley et al., 2011). In the study of Headley et al. (2011) the participants reached 3.7% greater maximal loads during the 1RM test with the 2/0/2 tempo compared to the 4/0/2 tempo, what indicates that the tempo of movement affects 1RM test results. In addition to the tempo of movement used, other factors may affect the maximum amount of weight an individual can lift. Age, sex, limb lengths and circumferences, body mass, muscle mass, training routine and status, the rate of contractions, and the time distribution between eccentric and concentric phases could all possibly influence the maximal load able to be lifted in a specific exercise (Reynolds et al., 2006).

Considering that the extension of the eccentric (ECC) phase of movement by 2 s (2/0/2 vs. 4/0/2) caused a 3.7% decrease in results of the 1RM test (Headley et al., 2011), it can be hypothesized that an additional extension of the duration of the ECC phase would induce further decreases in 1RM testing performance compared to a faster movement tempo. However, there is limited available data that evaluates such differences, especially with slow tempos of movement.

Therefore, the aim of this study was to determine the effects of different movement tempos, with changes only in the duration of the ECC phase of movement during the bench press exercise (BP) on 1RM test results. Our initial hypothesis was that the movement tempo would have a significant impact on the maximal load lifted in the 1RM test.

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Key points

- The tempo of movement during resistance exercise impact on the result of 1RM test. The longer duration of ECC phases affects the lower value of 1RM test result.
- Significant differences in result of 1RM were observed between the 2/0/X, 4/0/X and 6/0/X tempos.
- The 1RM test procedure should include information about the movement tempo used during the trial.
- When different movement tempos are used in test protocols, the 1RM test should be performed independently for each tempo.

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of 1RM test. A longer duration of each repetition increased time under tension, indicating a greater physiological demand during its execution, what may affects 1RM test results while using the slower tempo of movement. Therefore, the 1RM test procedure should include information about the movement tempo used during the trial. Furthermore, when different movement tempos are used in test protocols, the 1RM test should be performed independently for each tempo. Future research should also compare the effects of different duration of CON phase or changes in duration of both ECC and CON phases on the level of 1RM test results.

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significantly lower compared to the 4/0/X (ECC_{MED}) and 2/0/X tempo (ECC_{FAS}). Furthermore, results of the 1RM test in the 4/0/X tempo (ECC_{MED}) were also significantly lower compared to the 2/0/X tempo (ECC_{FAS}).

The results of our study show that the longer duration of the ECC phase, the greater the decrease in the result of the 1RM test, that supported our hypothesis. The results are also consistent with Headley et al. (2011) who observed that changes in the tempo of movement influenced the maximal load lifted in the 1RM test. In the study of Headley et al. (2011) participants lifted greater maximal loads during the 1RM test with a 2/0/2 tempo compared to the 4/0/2 tempo. However, additional extending of duration of the ECC phase of movement resulted in a further decrease of the maximal load reached in the 1RM test. It can be thus assumed that additional prolongation of the eccentric phase, for example up to 10 second as in another study of Hatfield et al. (2006) would cause an additional decrease in the value of 1RM results.

The main factor influencing 1RM test results considering different tempos of movement is the duration of effort during the ECC phase of movement. In our experiment, this phase lasted 2, 4, and 6 second for the ECC_{FAS}, ECC_{MED} and ECC_{SLO} tempo, respectively. It has been found that significantly greater duration of effort, especially in the ECC phase of movement, can lead to greater muscle exhaustion and consequently premature exercise fatigue (Schoenfeld et al., 2015). Three times longer duration of effort during the ECC_{SLO} compared to the ECC_{FAS} tempo, indicates a higher time under tension (TUT) in the ECC_{SLO} tempo which is related to greater energy expenditure during the longer ECC contraction and greater fatigue, what significantly decreases the load lifted in the 1RM test (Suchomel et al., 2019).

The higher result of the 1RM test during a faster tempo compared to slower, can be related not only to the duration of effort in the ECC phase of movement, but also to a more effective use of elastic energy generated during the faster ECC contraction, which is released during the CON phase of the movement (Cronin et al., 2001; Cronin and Henderson, 2004; Newton et al., 1997). Previous research has shown decreases in bar velocity, when the slower ECC phase was used, what was partially linked to less efficient utilization of the stretch-shortening cycle (SSC) (Wilk et al., 2019). Similar relationships were observed when analyzing the effects of post-activation potentiation, which was less effective when slow ECC phases were used in the activation protocol (Wilk et al., 2020). Therefore, a slower movement tempo in the ECC phase presumably increased metabolic fatigue compared to a faster tempo, which may reduce the efficiency of the SSC, and can be partly related to a lower 1RM result.

However, it should be noted that despite significant differences in 1RM test results between ECC_{FAS}, ECC_{MED} and ECC_{SLO}, the real difference (kg) in the results of 1RM between ECC_{FAS}, ECC_{MED} and ECC_{SLO} was rather small, reaching between 0 to 2.5kg between ECC_{MED} and ECC_{SLO} tempos and 2.5 to 5kg between the ECC_{FAS} and ECC_{SLO} tempos. While such a difference in results of the 1RM test may be considered small under real life conditions, it can be of great significance in training and competition of elite athletes, especially in competitions where success depends on maximal strength (Grgic et al., 2019). Further, it can be assumed that the use of a similar test procedure in a group of men with a high level of strength may significantly increase the real differences (kg) in 1RM test results between particular movement tempos, which requires further research.

Furthermore, the relatively small changes in the results of the 1RM test, especially between the ECC_{FAS} and ECC_{MED} tempo of movement, with increased TUT at a similar exercise load could be beneficial for muscle hypertrophy. Bird et al. (2005) and Burd et al. (2012) suggested that a longer TUT may be beneficial for inducing hypertrophy, especially with a slower ECC phase of movement (Schoenfeld, 2010). A longer TUT causes greater muscular tension, with a higher stress on a small number of active fibers, leading to greater muscle damage (Schoenfeld, 2010), what increases acute mitochondrial, sarcoplasmic and myofibrillar protein synthesis after resistance exercise, stimulating hypertrophy (Burd et al., 2012). Furthermore, a longer TUT promotes compressed blood vessels for a longer period of time that leads to vascular occlusion and additional metabolic stress factor, contributing to increased hypertrophy (Wilk et al., 2018b). Thus, even when the slower tempo of movement causes a slight decrease in 1RM test results, the benefits from increased TUT may be more significant for adaptation following resistance exercise.

The results of this study are of significance not only with regard to the procedure and the result of the 1RM test, but also to the procedure of scientific research. In the research procedures describing the impact of a movement tempo on acute and chronic changes in resistance training, specific values of %1RM are commonly used (Wilk et al., 2018a; Mike et al., 2017). However, if %1RM values were calculated based on the 1RM test with a volitional movement tempo, these values would not be reliable in training with a slower movement tempo.

The present study has several limitations, which should be addressed. Although the results showed significant differences in the result of the 1RM test between used movement tempos, the direct causes of these changes cannot be directly determined and explained. The research does not indicate whether the main effect occurred due to the higher eccentric component velocity or as a result of an efficient use of kinetic power output associated with the stretch-shortening cycle movements. There was no analysis of direct physiological changes that would be the basis for explaining the obtained results. Furthermore, during testing, the maximal velocity (X) in the CON movement was not measured, which does not allow for determination what was the real value of maximal velocity during the 1RM test with different movement tempos. Another limitation of the study was that the 1RM test was performed using universally standardised grip width, and the use of self-selected grip or close-grip could have caused influenced the results. This aspect requires further research.

Conclusion

The results of presented study showed that the tempo of movement during resistance exercise impact on the result the Tukey's test. Percent changes and 95% confidence intervals were also calculated. Effect sizes (Hedges' *g*) were reported where appropriate. Parametric effect sizes were defined as: large ($g > 0.8$); moderate (g between 0.8 and 0.5); small (g between 0.49 and 0.20) and trivial ($g < 0.2$).

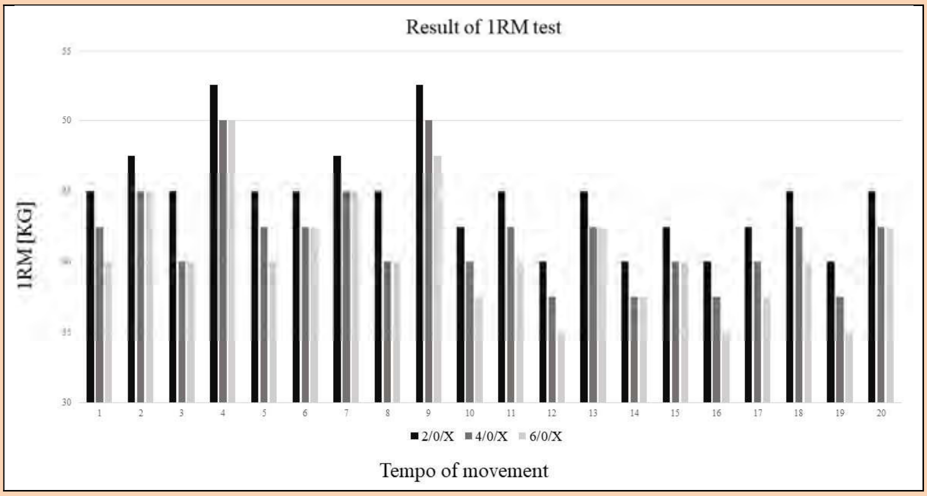

Figure 1. The individual results of the 1RM test with different movement tempos. Data are presented as result of 1 RM (kg) (as shown on the y-axis). Individual participants, numbered 1-20, are shown on the x-axis.

Table 1. Differences between the results of the 1RM test with different movement tempos. Data are presented as mean ± standard deviation.

	Movement tempo during the 1RM test			
	2/0/X (95% CI)	4/0/X (95% CI)	6/0/X (95% CI)	*p*
Maximal load in the 1RM test [kg]	44.6 ± 3.5 (42.96 to 46.29)	41.8 ± 3.6 (40.18 to 43.57)	40.6 ± 4.4 (38.73 to 42.52)	0.01*

*statistically significant differences p < 0.05.

Table 2. Summary of the study comparisons between the conditions. Data are presented as mean ± standard deviation.

Variable	Comparisons between tempos [kg]		*p*	Effect size Hedges' g (95% CI)	Relative effects [%]
Maximal load in the 1RM test [kg]	44.6 ± 3.5 (2/0/X)	41.8 ± 3.6 (4/0/X)	0.01*	0.77 (0.15 to 1.40) moderate	6.2 ± 1.7
	44.6 ± 3.5 (2/0/X)	40.6 ± 4.4 (6/0/X)	0.01*	0.99 (0.33 to 1.63) large	9.1 ± 3.1
	41.8 ± 3.6 (4/0/X)	40.6 ± 4.4 (6/0/X)	0.01*	0.29 (-0.32 to 0.90) small	3.1 ± 3.2

*statistically significant differences p < 0.05.

Results

The ANOVA with repeated measures revealed a statistically significant difference in 1RM ($p < 0.01$; Table 1) between tempos 2/0/X, 4/0/X and 6/0/X. Next, the post-hoc test showed the maximal load in the 1RM test was significantly higher during the BP with the 2/0/X tempo compared to 6/0/X ($p < 0.01$) (Table 2). The result of 1RM test during the BP with the 2/0/X tempo was significantly higher compared to 4/0/X tempo ($p < 0.01$) (Table 2). Furthermore, the result of 1RM test during the BP with the 4/0/X tempo was significantly higher compared to 6/0/X tempo ($p < 0.01$) (Table 2; Figure 1).

Discussion

The main finding of the present study is that increased duration of the eccentric phase of movement led to significant decreases in the maximal load reached in the 1RM test. The results of the 1RM test in the 6/0/X tempo (ECC_{SLO}) were

Methods

The purpose of the study was to determine whether there was a significant difference in the maximal load obtained during the 1RM test using different movement tempos. All testing was performed in the Strength and Power Laboratory at the Jerzy Kukuczka Academy of Physical Education in Katowice. The experiment was conducted following a randomized crossover design, where each participant performed three familiarization sessions and three different testing protocols 7 days apart. During each experimental session, participants completed the 1RM test protocol using the bench press (BP) exercise with different tempos: 2/0/X eccentric fast tempo (ECC_{FAS}), 4/0/X eccentric medium tempo (ECC_{MED}) and 6/0/X eccentric slow tempo (ECC_{SLO}). For example, the 2/0/X tempo denotes a 2 s ECC phase, no pause during the transition phase (0), "X" represents the maximum possible movement tempo during the CON phase. Participants were required to refrain from resistance training 72 hours prior to each experimental session, were familiarized with the exercise protocol and informed about the benefits and risks of the experiment before expressing their written consent for participation in the study.

Study participants

Twenty-one healthy strength trained females (age = 23.4 ± 2.2 years, body mass = 52.3 ± 6.7 kg), with a minimum one year of strength training experience (2.3 ± 1.47 years) took part in the research. Participants were free of any pathologies and injuries and were instructed to maintain their normal dietary habits over the entire study period and not to use any dietary supplements or stimulants for the duration of the study. In order to exclude the effect of motor learning, at least 3 weeks before the study, all participants practiced the bench press exercise with different movement tempos. Prior to study commencement, participants provided written informed consent; they were also allowed to withdraw from the experiment at any moment. This study was carried out in accordance with the recommendations of the ethical standards outlined in the Declaration of Helsinki, 2013. The protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland (10/2018).

Procedures

Familiarization session

Three weeks before the main experiment, the participants performed familiarization sessions once per week. During the familiarization sessions the participants performed 4 sets of 1 repetition of the BP against a load of ~ 80% 1RM. Two sets were performed with tempo 4/0/X and two sets with tempo 6/0/X. One week before the main experiment 1RM testing was performed. Participants arrived at the laboratory at the same time of day as the upcoming experimental sessions and cycled on an ergometer for 5 minutes at an intensity that resulted in a heart rate of approximately 130 bpm, followed by a general upper body warm-up. Next, participants performed 15, 10, 5 and 3 BP repetitions using 20, 40, 60, and 70% of their estimated 1RM, respectively, with a volitional tempo of movement. Hand placement on the barbell was set at 150% individual bi-acromial distance. Participants then executed single repetitions with a 5 min rest interval between successful trials. The load for each subsequent attempt was increased by 1.25 to 5 kg, and the protocol was repeated until failure.

Experimental sessions

The general and specific warm-up for the experimental sessions was identical to the one used for the familiarization session. The specific BP part of the warm-up was performed with a volitional tempo. Starting from a load of 80%1RM all sets were performed in one of the randomly selected tempos of movement. The participants unracked the bar with assistance of a spotter if required, and began the lift with the arms extended and elbows locked (Algra, 1982). The 'touch-and-go' procedure was adopted, in that the bar was required to touch the chest before being pressed to full arm extension (Lockie et al., 2017). In each subsequent attempt, the load was increased by 2.5 to 5 kg. A repetition was deemed to be successful when the bar was moved from the chest to a position of full elbow extension (Lockie et al., 2017). Failure to do this, or bouncing the bar on the chest, disqualified a repetition. A spotter was positioned behind the bar for assistance with lift-off if required and for safety, but did not touch the bar except in the event of a failed lift (Clemons and Aaron, 1997).

Participants executed single repetitions in each subsequent set, using a randomly selected tempo of movement:

- 2/0/X eccentric fast tempo
- 4/0/X eccentric medium tempo
- 6/0/X eccentric slow tempo

The rest interval between sets was 5 min, and all 1RM values were obtained within four attempts. The tempo of the eccentric phase was guided by a metronome (Korg MA-30, Korg, Melville, New York, USA). The concentric phase of the BP movement was performed at maximal possible velocity (X). All experimental sessions were recorded by means of a Sony camera (Sony FDR191 AX53). The duration of the eccentric phase of movement was assessed immediately after the completion of each repetition (from recorded data using slow speed playback) to check that the duration was compliant with the required tempo. In order to ensure high reliability of data collection, four independent, experienced researchers performed data analysis from the Sony camera. All participants completed the described testing protocol.

Statistical analysis

All statistical analyses were performed using Statistica 9.1 and Microsoft Office, and results were presented as means with standard deviations. The Shapiro-Wilk, Levene and Mauchly´s tests were used in order to verify the normality, homogeneity and sphericity of the sample data variances, respectively. The ANOVA with repeated measures were used to compare the differences between analyzed variable. Significance was set at $p<0.05$. In the event of a significant main effect, post hoc comparisons were conducted using

PRACA NR 4

„Fast Eccentric Movement Tempo Elicits Higher Physiological Responses than Medium Eccentric Tempo in Ice-Hockey Players"

W ostatnim badaniu analizie poddano wpływ zmiany czasu trwania powtórzenia na powysiłkowe reakcje hormonalne wśród profesjonalnych zawodników hokeja na lodzie. Ocena powysiłkowych zmian stężenia wybranych hormonów w odniesieniu do zmiennego tempa powtórzenia stanowiła główny problem badawczy artykułu *„Fast Eccentric Movement Tempo Elicits Higher Physiological Responses than Medium Eccentric Tempo in Ice-Hockey Players"* opublikowanego w czasopiśmie *„International Journal of Environmental Research and Public Health". w* badaniu wzięło udział 14 zawodników hokeja w wieku 26.2 ± 4.2 lat, o masie ciała 86.4 ± 10.2 kg, doświadczeniem w treningu oporowym 8.2 ± 4.2 lat, poziomem siły mięśniowej w przysiadzie ze sztangą 130.5 ± 18.5 oraz w wyciskaniu sztangi leżąc na płaskiej ławce 100.6 ± 13 kg. w sesji eksperymentalnej procedura badawcza obejmowała wykonanie 5 serii przysiadu ze sztangą oraz wyciskania sztangi leżąc o maksymalnej liczbie powtórzeń, stosując obciążenie zewnętrzne o wartości 80% 1-RM oraz 3-minutową przerwą wypoczynkową między seriami. Procedura badawcza zakładała zastosowanie tempa powtórzenia o wartości 2/0/2/0 lub 6/0/2/0. w trakcie trwania sesji eksperymentalnej rejestrowano liczbę wykonanych powtórzeń (REP) oraz czas trwania napięcia mięśniowego (TUT), poziom generowanej mocy mięśniowej kończyn górnych i dolnych oraz spoczynkowe i powysiłkowe zmiany stężenia hormonów: testosteron, hormon wzrostu, kortyzol oraz insulinopodobny czynniki wzrostu IGF-1. Analiza stężenia wybranych hormonów przeprowadzona została w spoczynku, w 3 minucie po zakończeniu ostatniej serii przysiadów ze sztangą, w 3 minucie po zakończeniu ostatniej serii wyciskania sztangi leżąc oraz po 30 minutach odpoczynku. Co szczególnie ważne zgodnie z wiedzą autora były to pierwsze badania, w których udział brali zawodnicy dotychczas regularnie stosujący zmienne tempo powtórzenia w treningu oporowym. Wcześniejsze badania oceniające wpływ zmiennego czasu trwania powtórzenia realizowane były wśród grup badawczych, które nie stosowały wcześniej zmiennego tempa powtórzenia, co może mieć istotne znaczenie w ocenie wpływu tej zmiennej na bezpośrednie i długofalowe zmiany adaptacyjne. Ponadto ponownie zgodnie z wiedzą autora badania te były pierwsze na świecie, w ramach których procedura testu 1-RM została niezależnie przeprowadzona dla każdego badanego tempa powtórzenia.

Hipoteza badawcza zakładała, że zmiana czasu trwania fazy ekscentrycznej wysiłku (2s vs. 6s) znacząco wpływa na wartość liczby powtórzeń, czas trwania napięcia mięśniowego oraz na powysiłkowe zmiany stężenia badanych hormonów (kortyzol, testosteron, GH oraz IGF-1). do oceny objętości wysiłku zastosowano sumę liczby powtórzeń oraz sumę TUT zarówno w serii, jak i w całym ćwiczeniu.

Wyniki badań wykazały, że czas trwania ekscentrycznej fazy ruchu wpływa na wartość wykonanej liczby powtórzeń oraz czas trwania napięcia mięśniowego w serii oraz w całym ćwiczeniu zarówno w podczas wyciskania sztangi leżąc, jak i przysiadzie ze sztangą, co jest zgodne z wcześniejszymi wynikami badań przedstawionych w pracach. Zgodnie ze wcześniejszymi wynikami badań, potwierdzono także zależność, że wraz z wydłużeniem czasu trwania fazy ekscentrycznej (6s) zwiększa się wartość TUT, ale jednocześnie zmniejsza maksymalna liczba wykonanych powtórzeń. Odwrotna sytuacja miała miejsce, gdy skrócono czas trwania fazy ekscentrycznej do 2s, w efekcie czego zwiększała się maksymalna wartość liczby powtórzeń w serii, ćwiczeniu i całej jednostce treningowej, lecz jednocześnie spadła maksymalna wartość TUT. Wykazane zależności pomiędzy czasem trwania fazy ekscentrycznej ruchu, a maksymalną liczbą powtórzeń oraz wartości TUT dotyczą zarówno przysiadów ze sztangą, jak i wyciskania sztangi leżąc, co potwierdza założoną hipotezę badawczą.

Ponadto badania wykazały, że powysiłkowe zmiany stężenia IGF-1, GH oraz kortyzolu były wyższe podczas protokołu, w którym wykorzystano krótki czas trwania fazy ekscentrycznej (2s), w porównaniu z długim czasem trwania fazy ekscentrycznej (6s), co jest sprzeczne z wcześniejszymi badaniami w tym zakresie (Calixto i wsp., 2014; Goto i wsp., 2008; Goto i wsp., 2009). Wyniki badań nie wykazały istotnych powysiłkowych różnic w stężeniu testosteronu po treningu oporowym z wykorzystaniem zmiennego czasu trwania fazy ekscentrycznej ruchu. Wyniki dotyczące powysiłkowych zmian stężenia hormonów są sprzeczne z wcześniejszymi badaniami, w których autorzy nie wykazują różnic odpowiedzi hormonalnych między różnym czasem trwania powtórzenia (Headley i wsp., 2011; Smilios i wsp., 2014; Wilk i wsp., 2021), a także z badaniami, które wskazują, że zastosowanie dłuższego czasu trwania powtórzenia zwiększa odpowiedź hormonalną (Goto i wsp., 2008, 2009; Wilk i wsp., 2018a).

Wcześniejsze doniesienia naukowe wykazują, że wydłużenie czasu trwania powtórzenia, szczególnie w fazie ekscentrycznej wpływa na wzrost powysiłkowego stężenia testosteronu oraz hormonu wzrostu (Goto i wsp., 2008, 2009; Calixto i wsp., 2014; Wilk i wsp., 2018a). Różnice między wcześniejszymi doniesieniami, a wynikami prezentowanego badania mogą być związane z doświadczeniem w treningu oporowym ze zmiennym tempem powtórzenia oraz ze specyfiką uprawianej dyscypliny sportowej. Należy szczególnie zwrócić uwagę na fakt, że opisywane badania są pierwszymi na świecie, które dokonały oceny wpływu zmiennego czas trwania fazy ekscentrycznej na poziom bezpośrednich powysiłkowych reakcji hormonalny, ale w grupie zawodników regularnie stosującej trening z kontrolowanym czasem trwania fazy powtórzenia. Wydaje się, że właśnie doświadczenie w treningu oporowym ze zmiennym tempem ruchu może być kluczowym aspektem w ocenie wpływu zmiennego czasu trwania powtórzenia zarówno na poziom bezpośrednich, jak i długofalowych zmian adaptacyjnych, co jest istotnym wnioskiem z opisywanego badania.

Protokół badania, w którym zastosowano krótszy czas trwania fazy ekscentrycznej wywołał większe zmęczenie mięśniowe analizowane na podstawie spadku wartości generowanej mocy mięśniowej, co może mieć związek z wykonaną liczbą powtórzeń. Grupa, w której wykorzystano tempo powtórzenia 2/0/2/0 wykonała istotnie wyższą liczbę powtórzeń w serii jak i ćwiczeniu, w porównaniu do grupy stosującej tempo powtórzenia 6/0/2/0. Tym samym w tempie powtórzenia 2/0/2/0 całkowita praca w fazie koncentrycznej ruchu także była istotnie większa, co może częściowo tłumaczyć wyższy spadek mocy mięśniowej mierzonej w fazie koncentrycznej ruchu. Dodatkowo wyniki badań wskazują, że wydłużenie czasu trwania wysiłku (TUT), jakie zaobserwowano podczas procedury z zastosowaniem tempa powtórzenia 6/0/2/0 nie zapewnia wyższego poziomu powysiłkowych odpowiedzi hormonalnych w grupie hokeistów. Wynik ten sugeruje, że przyzwyczajenie do treningu ze zmiennym tempem powtórzenia może istotnym czynnikiem mającym wpływ na poziom powysiłkowych metabolicznych i hormonalnych zmian, czego żadne wcześniejsze badania naukowe nie brały pod uwagę. z tego punktu widzenia artykuł ten można stanowić przełomowe znaczenie w zrozumieniu roli zmiennego tempa powtórzenia w procesie adaptacji mięśniowej.

Chociaż powysiłkowe stężenie kortyzolu (hormonu katabolicznego) wzrosło w obu protokołach, to jednak należy zwrócić uwagę na fakt, że wyższe zmiany zaobserwowano w protokole z wykorzystaniem tempa 2/0/2/0, w porównaniu do tempa 6/0/2/0, co jest sprzeczne z dotychczasowymi sugestiami wskazującymi, że wolniejsze tempo powtórzenia powoduje wyższe powysiłkowe reakcje metaboliczne i hormonalne, w porównaniu do tempa szybkiego. Co więcej wyniki badań wskazały, że dłuższy czas trwania powtórzenia (6/0/2/0) powoduje niższe powysiłkowe odpowiedzi hormonalne, w porównaniu z krótkim czasem trwania powtórzenia (2/0/2/0).

Wyniki przeprowadzonego badania wskazują, że czas trwania fazy ekscentrycznej ruchu znacząco wpływa na wartość liczby powtórzeń, wartość TUT oraz odpowiedzi hormonalnych podczas oraz po wysiłku z zastosowaniem ćwiczeń oporowych. Jednakże należy zwrócić szczególną uwagę, że przeprowadzone badania są pierwszymi dostępnymi w literaturze światowej w ramach którego wykorzystano profesjonalnych sportowców oraz fakt, że uczestnicy badania byli zaadoptowani do treningu oporowego z wykorzystaniem zmiennego tempa powtórzenia. Dotychczasowe badania z zakresu wpływu zmiennego tempa powtórzenia na poziom powysiłkowych zmian metabolicznych i hormonalnych dotyczyły grup osób rekreacyjnie trenujących, lub zawodników nie mających doświadczenia w treningu ze zmiennym tempem powtórzenia, co może mieć istotny wpływ na uzyskiwane wyniki. Co więcej, powysiłkowe metaboliczne i hormonalne w wyniki zastosowania wolnego tempa powtórzenia obserwowane we wcześniejszych badaniach (Calixto i wsp., 2014; Goto i wsp., 2008, 2009; Wilk i wsp., 2018a, 2021) mogą wynikać z faktu, że wprowadzenie zmiany tempa powtórzenia samo w sobie jest nowym bodźcem wysiłkowym i stąd następuje istotny wzrost w powysiłkowych reakcjach układu hormonalnego. Wyniki uzyskane w badaniu mogą potwierdzać taką hipotezę, ponieważ zawodnicy biorący udział w opisywanym badaniu byli zaadoptowani do treningu ze zmiennym tempem powtórzenia, co może mieć kluczowe znaczenie w dalszej ocenie i analizie bezpośrednich i długofalowych zmian adaptacyjnych. Wyniki badań uzasadniają stosowanie w grupach zawodowych sportowców krótkiego czasu trwania fazy ekscentrycznej podczas planowania i programowania treningu oporowego w celu wywołania większego powysiłkowego wzrostu odpowiedzi hormonalnych, ponieważ może być ważnym czynnikiem wpływającym na zmiany adaptacyjne w kształtowaniu siły i hipertrofii mięśniowej. Jednakże protokół ćwiczeń z krótkim czasem trwania fazy ekscentrycznej wywoływał większe zmęczenie mięśniowe, co należy wziąć pod uwagę przy planowaniu okresów regeneracyjnych podczas poszczególnych mikrocykli treningowych.

Tym samym badanie wykazało, że liczba powtórzeń oraz wartość TUT są zależne od zastosowanego czasu trwania powtórzenia w ćwiczeniu oporowym. Dodatkowo wartość czasu trwania powtórzenia ma bezpośredni wpływ na poziom powysiłkowych reakcji hormonalnych. Jednakże biorąc pod uwagę całościowy stan dotychczasowej naukowej wiedzy w tym zakresie nie można jednoznacznie stwierdzić, czy wolne bądź szybkie tempo powtórzenia są korzystniejsze w dążeniu do wywołania powysiłkowych zmian hormonalnych. Wyniki badań sugerują konieczność określania czasu trwania fazy ekscentrycznej ruchu w zależności od oczekiwanej odpowiedzi hormonalnej, jednocześnie co jest najważniejszą implikacją przedstawionych badań, należy brać pod uwagę poziom doświadczenia w treningu ze zmiennym tempem powtórzenia. Biorąc pod uwagę częstość występowania ćwiczeń przysiadu ze sztangą oraz wyciskania sztangi leżąc w programach treningowych, przedstawione wyniki oraz implikacje praktyczne można odnieść do innych dyscyplin sportowych.

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Fast Eccentric Movement Tempo Elicits Higher Physiological Responses than Medium Eccentric Tempo in Ice-Hockey Players

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Abstract: Background: Resistance training is a significant part of ice-hockey players' conditioning, where optimal loading should ensure strength development and proper recovery. Therefore, this study aimed to compare the acute physiological responses to fast and medium movement tempo resistance exercises in ice-hockey players. Methods: Fourteen ice-hockey players (26.2 ± 4.2 years; 86.4 ± 10.2 kg; squat one repetition maximum (1RM) = 130.5 ± 18.5) performed five sets of the barbell squat and barbell bench press at 80% 1RM until failure in a crossover design one week apart using either 2/0/2/0 or 6/0/2/0 (eccentric/isometric/concentric/isometric) tempo of movement. The blood samples to evaluate the concentration of cortisol, testosterone, insulin-like growth factor 1 (IGF-1), and growth hormone (hGH) were taken before exercise, 3 min after the last set of the squat exercise, 3 min after the last set of the bench press exercise, and after 30 min of recovery. Results: The 2/0/2/0 tempo resulted in a higher number of repetitions ($p < 0.001$) and lower time under tension ($p < 0.001$) in the squat and bench press exercises compared to the 6/0/2/0 movement tempo. The endocrine responses to exercise were significantly higher during the 2/0/2/0 compared to the 6/0/2/0 movement tempo protocol for IGF-1, hGH, and cortisol ($p < 0.01$). There were no differences in testosterone responses between exercises performed with fast and medium movement tempos. Conclusion: Fast eccentric tempo induced higher cortisol, IGF-1, and hGH responses compared to the medium tempo. Therefore, fast eccentric movement tempo seems to be more useful in eliciting training stimulus than medium eccentric tempo during resistance training in ice-hockey players. However, future studies are needed to confirm our findings.

Keywords: cortisol; testosterone; insulin-like growth factor 1 (IGF-1); growth hormone (hGH); resistance training; conditioning

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1. Introduction

Resistance exercises are a crucial part of ice-hockey players' conditioning, where optimal loading should ensure strength development and recovery by increasing maximal strength and power output [1–3]. Furthermore, the level of strength and power output is an important predisposition to succeed at the elite NHL performance level [4]. The current knowledge on ice-hockey resistance training programs is apparent in regard to exercise intensity, load, rest intervals, and exercise selection [2,3,5] without detailed description of the optimal tempo of movement during such exercises [6]. Movement tempo in resistance exercise is usually described using a sequence of digits (e.g., 2/0/3/0), where each digit defines the duration of a particular phase of the movement using a four-digit combination: eccentric, isometric, concentric, and isometric [7–9]. According to the movement tempo classification, fast tempo is the duration of a single repetition between 2 and 5 s, medium movement tempo occurs when the duration of a single repetition is between 5 and 10 s, and slow movement tempo takes place when the duration of a single repetition is above 10 s [8].

Ice-hockey players perform 22.3 ± 4.9 shifts per game lasting about 45 s, where 23.0 ± 12.6% is covered by gliding, 42 ± 7.1% by slow skating [10], and 17.6 ± 6.0% by high-intensity skating, which requires high levels of anaerobic power 11.6 ± 1.3 (W/kg) [11]. The resistance training performed by ice-hockey players should maintain or increase non-specific conditioning levels, improve specific fitness, and ensure the physiological responses for proper recovery. Thus resistance training programs for hockey should elicit loading that stimulates optimal physiological and hormonal responses. The metabolites and hormonal accumulation during and after resistance training are the primary stimuli for changes in strength and muscle hypertrophy, where the key hormones in training adaptations are testosterone (T), growth hormone (GH), cortisol (C), and insulin-like growth factor 1 (IGF-1) [8]. Taking into account the post-exercise hormonal responses, optimal training loads should have a limited post-exercise response in cortisol levels, and at the same time an induced high post-exercise response of hGH, T, and IGF-1 [12]. It seems that these hormones and growth factors are influenced by resistance exercise movement tempo [8,12–14]. Previous research has shown that different movement tempos impact acute physiological responses, including hormone and blood lactate concentration [8]. It has been suggested that a medium movement tempo could increase the metabolic [15,16] and hormonal response provided by resistance exercise [8,14,17]. Medium movement tempo increases time under tension (TUT) during a set, which increases the volume of effort [13]. Higher volume protocols with medium movement tempo and greater metabolic demands lead to increased hormonal responses compared to faster movement tempo [18,19]. Furthermore, the physiological effect of medium movement tempo during resistance exercise can be similar to what occurs during resistance exercise with blood flow restriction [20]. The effects of exercise regimens with restricted muscular blood flow are likely mediated by the stimulated secretion of growth hormone and by intramuscular accumulation of metabolic byproducts, moderate production of reactive oxygen species promoting tissue growth, and additional recruitment of fast-twitch fibers under hypoxic conditions [20]. However, most studies about acute impact of different movement tempos were performed in recreationally trained subjects, while such assessments have not been performed in elite athletes who would be the most likely candidates for advanced resistance-training methods, such as varied movement tempo.

Off-ice ice-hockey conditioning requires knowledge about the specificity of the desired training conditions [2,3,5,21–24], where, e.g., the ice-hockey take-off is performed in a more extended period (0.33 s) than movements such as sprint ice skating (0.08–0.25 s), or single leg hops (0.124 s) [23]. Since ice-hockey players spend approximately 39% of the match in a two-foot glide position [24], their on-ice sprint conditions are related to bilateral squat and jump performance [4,25], thus resistance training that includes squats can improve on-ice sprint skating [26]. Upper limb strength in ice-hockey players is typically evaluated by the bench press performance [4,10,11], while the bench press exercise belongs to the main complex exercises used in off-ice resistance training [3]. Although there is a general agreement in selecting squats and bench press for off-ice training, there is a lack of empirical data on the optimal duration of the eccentric phase of the movement. It has been shown that changes in the eccentric movement duration can influence acute hormonal and kinematic responses and may provide significant strength training variability [13]. Therefore, different movement tempo may be an essential factor in resistance training performed by ice-hockey players, who are highly adapted to isometric and controlled eccentric contractions during ice skating [23,27,28].

While the total number of studies related to the impact of different movement tempo is relatively high, there is a lack of research representing particular populations, especially people advanced in resistance training and competitive athletes [9]. Only a small number of studies included highly trained athletes, who would be the most likely candidates for movement tempo occurs when the duration of a single repetition is between 5 and 10 s, and slow movement tempo takes place when the duration of a single repetition is above 10 s [8].

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While the total number of studies related to the impact of different movement tempo is relatively high, there is a lack of research representing particular populations, especially people advanced in resistance training and competitive athletes [9]. Only a small number of studies included highly trained athletes, who would be the most likely candidates for advanced resistance-training methods, such as varied movement tempo resistance training [8,9]. Currently only two studies have considered acute impact of different movement tempos during resistance exercise on post-exercise hormonal responses in subjects with significant resistance training experience. Wilk et al. [13] showed that post-exercise increases of testosterone were greater after the bench press exercise (5 sets, maximal number of performed repetitions, load 70% 1RM) performed with a medium compared to a fast movement tempo (6/0/2/0 vs. 2/0/2/0) in subjects with at least five years of resistance training experience (5.7 $\pm$ 1.29 years). In contrast, Wilk et al. [14] did not show changes in post-exercise hormone concentrations (T, hGH, cortisol, IGF-1) after the squat exercise (5 sets, maximal number of performed repetitions, load 80% 1RM) performed with medium vs. fast tempo of movement (5/0/3/0 vs. 2/0/2/0) in a group of powerlifters. Therefore the type of exercise can be a significant factor influencing acute post-exercise hormonal responses following exercise performed with different movement tempos. However, currently there are no studies regarding the impact of movement tempo on acute post-exercise hormonal changes during a research protocol containing simultaneously squat and bench press exercises, two basic exercises for developing strength and power output of the upper and lower limbs. Furthermore, there are also no studies related to the impact of different movement tempo on acute physiological responses with subjects habituated to resistance exercise performed with different movement tempos. Finally, there is a lack of studies regarding the acute effects of movement tempo on physiological responses in elite ice-hockey players.

Therefore, the objectives of the study were to compare the acute physiological responses of fast and medium eccentric movement tempo during resistance exercises in elite ice-hockey players. We hypothesized that the medium eccentric movement tempo would provide longer time under tension and greater acute hormonal responses than fast movement tempo.

2. Material and Methods

The experiment was performed in a randomized crossover design, where each participant performed eight familiarization sessions, one session of 1RM testing, and two main testing sessions 7 days apart. During each experimental session, the participants performed 5 sets of barbell squats (SQ) and 5 sets of the bench press exercise (BP) against a load of 80%1RM with different movement tempos: fast (2/0/2/0) or medium movement tempo (6/0/2/0), where the 6/0/2/0 movement tempo denotes a 6 s eccentric phase, no pause during the transition phase (0), a 2 s concentric phase, and 0 refers to no pause between the completion of the concentric phase and the beginning of the next eccentric phase (Figure 1). We decided to use the 2/0/2/0 movement tempo as the fast one based on previous results, which indicate that the ranges of volitional duration of the concentric movement in the squat and the bench press exercise at 80% 1RM were 0.76–1.29 and 0.90–1.93 s, respectively [29]. The medium eccentric tempo (6 s) has been chosen as duration regularly used by research participants in their current resistance training routines. The testing session also included a countermovement jump test (CMJ) before and after the SQ and the BP (2 min rest interval) to assess lower limb fatigue levels based on changes in power output. During the experiment, venous blood samples were collected from the antecubital vein. In each case, 10 mL of venous blood was drawn to determine pre-squat and post-exercise values of the following biochemical variables (cortisol, testosterone, GH, IGF-1). The blood samples were taken before exercise, 3 min after the last set of the squat exercise and the bench press exercise, and after 30 min of recovery. All familiarization and experimental sessions were performed during the off-season, and during the preparatory period to the regular season. The main experimental sessions were performed on the same day of the week (Monday), preceded by two days of rest. The routine training workout was maintained on the other days of the weekly microcycle.

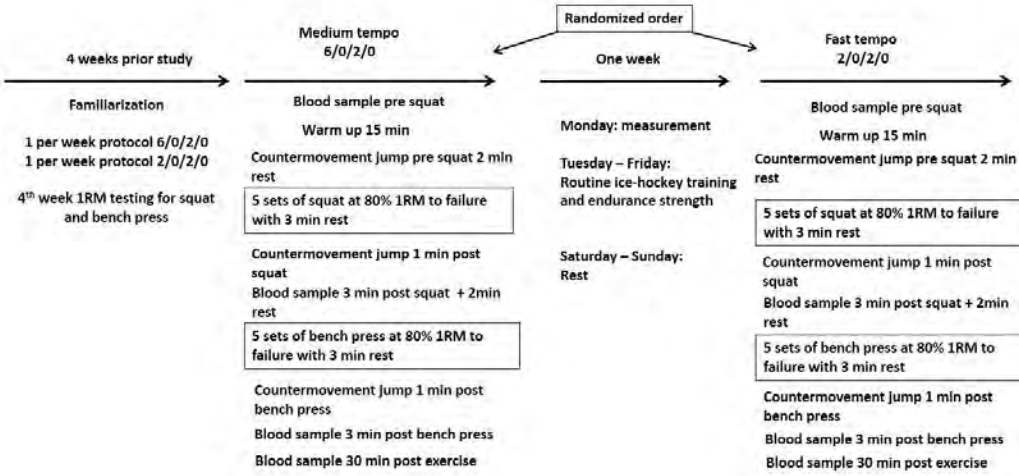

Figure 1. Flow chart of the experiment.

2.1. Participants

Fourteen athletes representing a professional first league ice-hockey team, experienced in resistance training (8.2 ± 4.2 years), volunteered for the study after completing an informed consent form (age = 26.2 ± 4.2 years; body mass = 86.4 ± 10.2 kg; SQ 1RM = 130.5 ± 18.5; BP 1RM = 100.6 ± 13.0 kg). Subjects were allowed to withdraw from the experiment at any moment and were free from musculoskeletal disorders. The subjects were instructed to maintain their normal dietary habits throughout the study and not to use any supplements or stimulants for the experiment's duration. Subjects were informed about the study's benefits and potential risks before providing their written informed consent for participation. The Bioethics Committee approved the study protocol for Scientific Research at the Academy of Physical Education in Katowice, Poland (10/2018) which was performed according to the ethical standards of the Declaration of Helsinki 2013.

2.2. Familiarization Session and 1RM Strength Test

Four weeks before the main experiment, the athletes performed familiarization sessions twice per week. During the familiarization sessions, the athletes performed resistance training including the squat and bench press exercises performed with a 2/0/2/0 or 6/0/2/0 tempo of movement. The familiarization sessions were conducted to restrict possible learning effects. One week before the main experiment 1RM testing was performed. The subjects arrived at the laboratory at the same time as the upcoming experimental sessions. They cycled on an ergometer for 5 min, followed by a general upper body warm-up of 10 bodyweight pull-ups and 15 bodyweight push-ups. Next, the subjects began the 1RM test for the SQ and BP exercises. The subjects performed 15, 10, and 5 SQ repetitions using 20%, 40%, and 60% of their estimated 1RM. The first testing load was set to an estimated 80% 1RM and was increased by 2.5 to 10 kg for each subsequent attempt. Then the subjects executed one repetition with a 5 min rest interval between successful trials, and repeated this process until failure. After a 10 min recovery period, the participants completed the 1RM test for the BP with an identical test protocol as for the SQ [13,29].

2.3. Experimental Sessions

The subjects performed the squat and the bench press exercise against a load of 80% 1RM either with 2/0/2/0 or 6/0/2/0 tempo of movement. In each exercise, the subjects performed 5 sets with a maximal number of repetitions with a metronome guided movement tempo in the eccentric and concentric phases (Korg MA-30. Korg. Melville. New York, NY, USA). The rest interval between sets was 3 min. The rest interval between exercises lasted 5 min. The interval between both experimental test protocols was 7 days to avoid the accumulation of fatigue. Time under tension and the number of performed repetitions were obtained manually from the recorded data. To ensure manual data collection reliability, four independent persons made the data analysis from the Sony camera. During the experimental sessions, the number of performed repetitions (REP) in particular sets of the squat (SQ-REP), and the bench press exercises (BP-REP) were recorded. The time under tension (TUT) in all 5 sets of the squat (SQ-TUT) and the bench press (BP-TUT) was also registered.

2.4. Squat Exercise

The position for the squat was controlled and was identical in every attempt. The athletes started from an upright position, with the knees and hips fully extended, the stance approximately shoulder-width apart with both feet positioned flat on the floor in parallel or externally rotated to a maximum of 15°. The bar rested across the back at the level of the acromion. Stance width and feet position were individually adjusted and carefully replicated on every lift. The bar was required to remain in contact with the back and shoulders at all times. From this position, they were required to descend until making contact the upper leg was horizontal [30,31].

Knee wraps and safety belts were not used. At all times during the testing protocol and warm-up sets, three spotters were present. The squat was performed with an Eleiko IPF barbell (2.9 cm diameter, length 1.92 m).

2.5. Bench Press Exercise

During the bench press test protocol hand placement on the barbell was set at 150% of the individual bi-acromial distance. The positioning of the hands was recorded to ensure consistent hand placement during all experimental sessions. The BP was performed with an Eleiko IPF barbell (2.9 cm diameter, length 1.92 m) and on an Eleiko competition bench [32].

2.6. Countermovement Jump Test

The participants were instructed to perform the CMJ on a force plate with maximal effort. The CMJ was measured using an AccuPower force plate (AMTI OR6-7-1000; Watertown, MA, USA), allowing ground reaction forces to be assessed with 1.000 Hz sampling to determine jump velocity and power output. The CMJ was performed with both hands on the waist while making a downward movement approximately to 90° knee flexion followed by a maximum effort vertical jump. The investigators also encouraged the athletes verbally for maximum performance to reach peak velocity (V_{max} in m/s) and peak power output (P_{max}, W/kg) [33,34]

2.7. Biochemical Analysis

During the experiment, venous blood samples were collected from the antecubital vein. In each case, 10 mL of venous blood was drawn to determine pre and post-exercise biochemical values of the analyzed variables (cortisol, testosterone, GH, IGF-1). The post exercise values were taken 3 min after the cessation of the last set of squats, 3 min after the cessation of the last set of the bench press, and after 30 min of recovery. Commercially available radioimmunoassay evaluations were performed for the assessment of testosterone ng/dl (Cobas), GH ng/mL (Immulite 2000 XPi), IGF-1 ng/mL (Immulite 2000 XPi), and cortisol μg/dl (Cobas). Each sample underwent six analyses to ensure accurate results.

2.8. Statistical Analyses

All statistical analyses were performed in STATISTICA software 13.3 (Tibco, Palo Alto, CA, USA) at alfa level 0.05. The biochemical analysis reliability was calculated by the intra-class correlation coefficient and data normality by the Shapiro Wilk test. The calculated sample size for non-inferiority and superiority tests in cross-over designs was n = 13 to achieve 80% power for both values at $\beta = 0.2$. The differences in the number of performed repetitions (repetition × set × tempo), TUT (TUT × set × tempo), fatigue (CMJ × set × tempo), and biochemical markers (biochemical value × set × tempo) were analyzed with the repeated measures ANOVA. The ANOVA $p < 0.05$ and result of Tukey post hoc test was considered significant at effect size determined by partial eta square η^2 classified according to Larson-Hall [35] and Cohen [36], where η^2: 0.02, 0.13, 0.26 were considered as small, moderate, and large effects respectively. Cohen *d* was used to express the effect size between each condition due to fatigue and biochemical markers considering d 0.2, 0.5, 0.8, 1.2 as small, medium, large, and very large effect, respectively.

3. Results

There were no significant differences in the SQ-REP [n]; BP-REP [n]; SQ-TUT [s]; BP-TUT [s] between the data collected by four evaluators. The data normality was not disrupted, and the descriptive values of jumping fatigue, and biochemical markers are presented as mean values and standard error (Table 1), where baseline (pre-exercise) values did not differ between tempo protocols. The ICC for the biochemical analysis varied from 0.88 to 0.99 for the 6 samples and were considered valid.

Table 1. Endocrine and neuromuscular responses to fast (2/0/2/0) and medium tempo (6/0/2/0) exercise protocols.

	Medium TEMPO				Fast TEMPO			
	Pre-Squat	Post-Squat	Post-Bench Press	Post-Session 30 min	Pre-Squat	Post-Squat	Post-Bench Press	Post-Session 30 min
CMJ Vmax (m/s)	2.93 ± 0.05; 2.81–3.04	2.83 ± 0.04; 2.72–2.94	2.85 ± 0.06; 2.73–2.96	–	2.98 ± 0.06; 2.86–3.09	2.75 ± 0.06; 2.64–2.87	2.82 ± 0.06; 2.71–2.94	–
CMJ Pmax (W/kg)	34.36 ± 1.43; 31.16–37.56	33.31 ± 1.27; 30.12–36.49	32.40 ± 1.55; 29.49–35.31	–	35.90 ± 1.69; 32.70–39.10	31.33 ± 1.81; 28.15–34.52	31.63 ± 1.28; 28.73–34.54	–
Cortisol (μg/dL)	13.74 ± 1.45; 10.59–16.87	16.76 ± 0.88; 14.84–18.66	18.08 ± 1.15; 15.59–20.57	14.08 ± 0.94; 12.04–16.13	14.30 ± 1.45 11.33–17.27	18.72 ± 1.43; 16.26–21.17	23.76 ± 1.55; 20.95–26.57	20.32 ± 1.75; 17.42–23.22
GH (ng/mL)	0.52 ± 0.35; −0.24–1.27	7.20 ± 1.92; 3.04–11.34	4.59 ± 1.16; 2.06–7.11	1.76 ± 0.52; 0.65–2.88	0.15 ± 0.05; 0.04–0.27	11.21 ± 2.75; 5.26–17.15	10.23 ± 1.98; 5.96–14.50	3.43 ± 0.78; 1.73–5.12
IGF-1 (ng/mL)	202.43 ± 14.25; 171.79–233.07	222.07 ± 13.54; 192.81–251.32	211.29 ± 13.96; 181.11–241.46	200.00 ± 14.08; 169.57–230.42	212.14 ± 15.53; 178.58–245.70	249.50 ± 10.85; 226.05–272.95	210.43 ± 15.74; 176.42–244.43	233.07 ± 7.91; 215.99–250.15
Testosterone (ng/dL)	492.10 ± 32.24; 422.42–561.76	663.43 ± 49.45; 556.58–770.28	615.01 ± 55.70; 494.68–735.34	539.05 ± 45.80; 440.08–638.01	488.90 ± 41.36; 399.69–578.19	690.27 ± 62.50; 555.23–825.30	649.91 ± 62.14; 515.65–784.17	521.81 ± 51.85; 409.80–633.82

Values are expressed as mean ± SE; 95% CI. GH = growth hormone, IGF-1 = insulin like growth factor, CMJ = countermovement jump test, Vmax = maximum concentric velocity, Pmax = maximum concentric power.

The ANOVA analyses for the number of repetitions was different for particular sets ($F_{12,208} = 4.1$, $p < 0.001$. $\eta^2 = 0.19$) and exercises ($F_{4,208} = 149$. $p < 0.001$. $\eta^2 = 0.82$). The post hoc tests showed that during the squat exercise the maximal number of performed repetitions was significantly higher in tempo 2/0/2/0 compared to 6/0/2/0 tempo in each set ($p < 0.01$), and during the bench press exercise the maximal number of performed repetitions was significantly higher in the 2/0/2/0 tempo compared to the 6/0/2/0 tempo in each set ($p < 0.001$; Figure 2).

The ANOVA showed that the TUT was different between sets ($F_{12,208} = 121$, $p < 0.001$. $\eta^2 = 0.82$) and exercises ($F_{4,208} = 83$. $p < 0.001$. $\eta^2 = 0.70$). The post hoc showed that the SQ-TUT in 6/0/2/0 tempo was significantly higher compared to the SQ-TUT 2/0/2/0 tempo in each set ($p < 0.01$), and the BP-TUT 6/0/2/0 was significantly higher compared to the BP-TUT 2/0/2/0 in each set ($p < 0.01$; Figure 2).

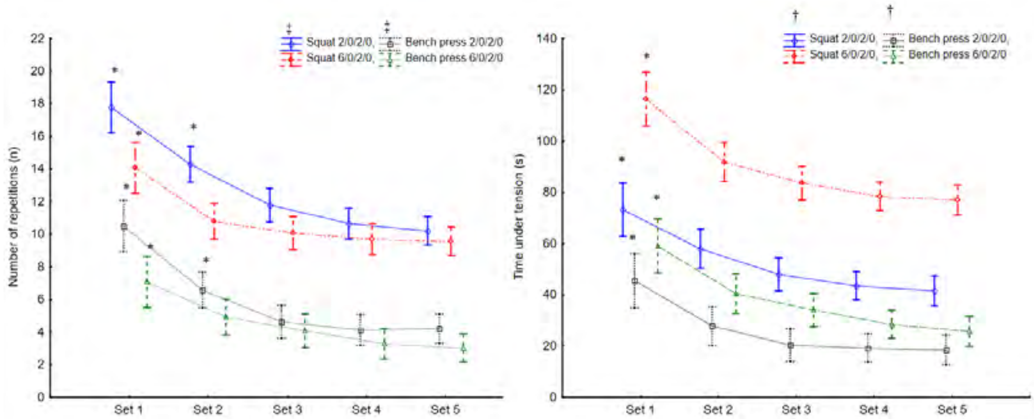

Figure 2. The number of repetitions and time under tension in all sets during the fast (2/0/2/0) and medium (6/0/2/0) squat and bench press protocol. * significantly higher ($p < 0.001$) than following set, ‡ significantly higher than 6/0/2/0 tempo protocol, † significantly lower ($p < 0.001$) than 6/0/2/0 TEMPO protocol. Values are expressed in mean and standard deviations.

The results of ANOVA for fatigue showed that results of the CMJ performance changed significantly in case of V_{max} ($F_{2,64} = 22$, $p < 0.001$, $\eta^2 = 0.41$) during the training sessions and were significantly different between exercise protocols ($F_{2,64} = 3.5$, $p < 0.034$, $\eta^2 = 0.09$). The post hoc tests showed a significant decrease in V_{max} after the squat exercise at both tempo protocols ($p < 0.01$), and the 2/0/2/0 tempo protocol resulted in a higher decrease compared to the 6/0/2/0 movement tempo protocol (Figure 3). After the bench press, the V_{max} in both tempo protocols was significantly lower compared to baseline results ($p < 0.01$), but the V_{max} post-bench press for the 2/0/2/0 tempo was significantly higher compared to post-squat results ($p < 0.01$; Figure 4).

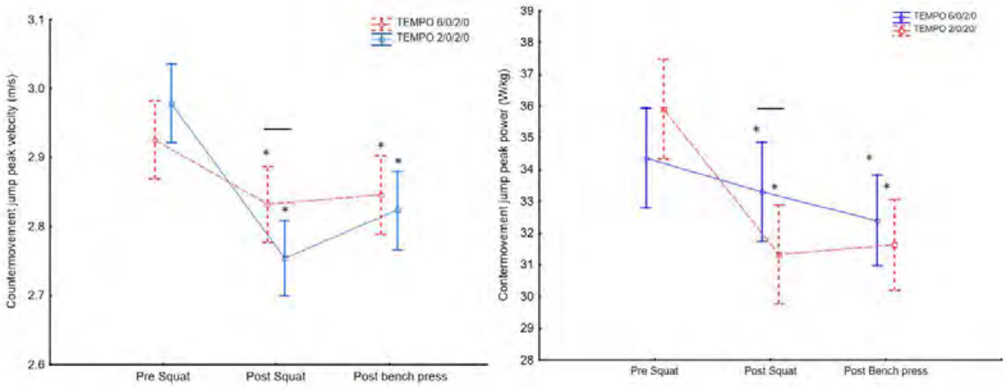

Figure 3. Fatigue in the countermovement jump, expressed as changes in velocity and relative peak power output during fast (2/0/2/0) and medium movement tempo (6/0/2/0) of the squat and bench press exercise protocols. * significantly lower ($p < 0.05$) than pre-squat values, dash-line shows significant differences ($p < 0.05$) between 6/0/2/0 and 2/0/2/0 protocols. Values are expressed in mean and standard deviations.

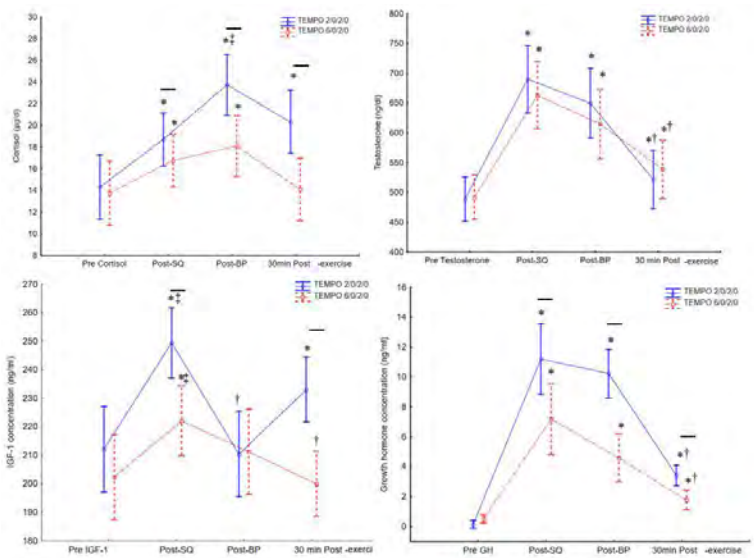

Figure 4. Cortisol, growth hormone, testosterone, and IGF-1 concentrations during the squat and bench press exercises with fast (2/0/2/0) and medium (6/0/2/0) movement tempo. * significantly higher ($p < 0.05$) than pre-squat values, dash-line shows significant differences ($p < 0.05$) between 6/0/2/0 and 2/0/2/0 protocols. ‡ significantly higher ($p < 0.05$) than all other values at the same protocol. † significantly lower ($p < 0.05$) than post-squat and post-bench press values, Values are expressed in mean and standard deviations. GH = growth hormone, IGF-1 = insulin-like growth factor 1.

Significant differences were found in the CMJ P_{max} ($F_{2,64} = 12$, $p < 0.001$, $\eta^2 = 0.27$) during the training sessions and between exercise protocols ($F_{2,64} = 3.3$, $p < 0.043$, $\eta^2 = 0.09$). The post hoc test showed that P_{max} significantly decreased after the SQ 2/0/2/0 tempo ($p < 0.01$; Figure 3), and the 2/0/2/0 tempo protocol resulted in significantly lower values compared to the 6/0/2/0 tempo protocol. After the BP exercise the P_{max} in both tempo protocols was significantly lower compared to baseline P_{max} ($p < 0.01$) and showed no differences compared to post-squat values (Figure 3, Tables 2 and 3).

Table 2. Cohen *d* effect sizes for endocrine and neuromuscular changes after fast (2/0/2/0) and medium tempo (6/0/2/0) exercise protocols.

Variable	Protocol TEMPO	Pre-Exercise Post-Squat	Post-Squat Post-Bench Press	Post-Squat Post-30 min	Pre-Exercise Post-Bench Press	Pre-Exercise Post 30 min	Post-Bench Press Post-30 min	Between TEMPO Difference Post-Squa t Post-Bench Press Post-30 min		
CMJ Vmax (m/s)	fast medium	0.9 0.5	0.3 0.1	- -	0.6 0.3	- -	- -	0.4	0.1	-
CMJ Pmax (W/kg)	fast medium	0.7 0.2	0.1 0.2	- -	0.7 0.3	- -	- -	0.3	0.2	-
Cortisol (µg/dL)	fast medium	0.7 0.7	0.9 0.3	0.4 0.8	1.6 0.9	1 0.1	0.3 2.9	0.5	1.2	1.2
GH (ng/mL)	fast medium	1.5 1.3	0.1 0.5	1.0 1.0	2.2 1.3	1.6 0.7	1.2 0.8	0.5	0.9	0.7
IGF-1 (ng/mL)	fast medium	0.8 0.4	0.8 0.2	0.5 0.4	0.0 0.2	0.5 0.00	0.5 0.2	0.6	0.0	0.8
Testosterone (ng/dL)	fast medium	1.0 1.1	0.2 0.2	0.8 0.7	0.8 0.7	0.2 0.3	0.6 0.4	0.1	0.2	0.1

GH = growth hormone, IGF-1 = insulin like growth factor, Vmax = maximum concentric velocity, Pmax = maximum concentric power.

Table 3. Endocrine and neuromuscular changes after fast (2/0/2/0) and medium tempo of resistance exercise protocols (6/0/2/0).

Variable	Protocol TEMPO	Pre-Exercise Post-Squat	Post-Squat Post-Bench Press	Post-Squat Post-30 min	Pre-Exercise Post-Bench Press	Pre-Exercise Post 30 min	Post-Bench Press Post-30 min
CMJ Vmax (m/s)	fast	−0.22 ± 0.15 −0.30–−0.14	0.07 ± 0.16 −0.01–0.14	-	−0.16 ± 0.18 −0.20–0.01	-	-
	medium	−0.09 ± 0.11 −0.15–0.04	0.02 ± 0.14 −0.08–0.06	-	−0.08 ± 0.12 −0.14–0.02	-	-
CMJ Pmax (W/kg)	fast	−4.57 ± 4.90 −7.09–−2.05	0.3 ± 4.09 −1.80–2.40	-	−4.27 ± 4.81 −6.75–−1.79	-	-
	medium	−1.05 ± 3.10 −2.64–0.54	−0.91 ± 3.49 −2.70–0.88	-	−1.96 ± 3.58 −3.80–0.11	-	-
Cortisol (µg/dL)	fast	4.42 ± 3.79 2.23–6.61	5.04 ± 3.57 2.98–7.10	3.44 ± 3.49 1.42–5.46	9,46 ± 5.25 6.43–12.49	6.02 ± 7.02 1.97–10.07	−3.44 ± 3.49 −5.46–−1.42
	medium	3.02 ± 3.97 0.73–5.32	1.32 ± 3.11 −0.47–3.12	−4.00 ± 0.07 −5.77–−2.22	4.34 ± 4.22 1.91–6.78	0.34 ± 4.08 −2.01–2.07	−4.00 ± 3.07 −5.78–−2.22
GH (ng/mL)	fast	11.05 ± 10.27 5.12–19.98	−0.97 ± 4.75 −3.71–1.77	−7.77 ± 7.95 −12.37–−3.18	10.08 ± 7.38 5.82–14.35	3.27 ± 2.92 1.58–4.96	−6.80 ± 4.63 −9.49–−4.13
	medium	6.67 ± 6.8 2.70–10.64	−2.60 ± 4.34 −5.11–−0.10	−5.43 ± 5.90 −8.84–−2.03	4.07 ± 4.00 1.76–6.38	1.25 ± 2.16 −0.01–2.50	−2.82 ± 3.56 −4.88–−0.76
IGF-1 (ng/mL)	fast	37.36 ± 60 2.69–72.02	−39.07 ± 68 −78–0.24	−16 ± 33.64 −35.86–2.99	1.71 ± 30 −15.97–19.39	20.92 ± 60 −14.15–56.01	22.64 ± 62 −13.26–58.55
	medium	19.64 ± 14.18 11.45–27.83	−10.78 ± 17.58 −20.93–0.63	−22.07 ± 11.51 −28.71–15.42	8.85 ± 19.02 2.23–19.95	−2.42 ± 12.08 −9.40–4.54	−11.28 ± 24.92 −25.67–3.1
Testosterone (ng/dL)	fast	201.37 ± 100 143–259	−40.36 ± 44.61 −66–−15	−168.46 ± 66 −206–−130	161.01 ± 112 95–226	32.91 ± 78 −13–78	−128.10 ± 67 −167–−90
	medium	171.32 ± 92 117–224	−48 ± 82 −95–−1	−124 ± 72 −166–−82	122 ± 120 53–192	46 ± 93 −7–100	−75 ± 72 −117–−34

Values are expressed as mean difference ± SD and 95% confidence limit–. GH = growth hormone, IGF-1 = insulin-like growth factor, CMJ = countermovement jump test, Vmax = maximum concentric velocity, Pmax = maximum concentric power.

Significant differences between cortisol concentration were found during and after the training sessions ($F_{3,78}$ = 24, $p < 0.001$, $\eta^2 = 0.48$) and between different movement tempo protocols ($F_{3,78}$ = 5.8, $p < 0.001$, $\eta^2 = 0.18$). The post hoc test showed that cortisol concentration significantly increased after the SQ exercise compared to baseline ($p < 0.01$), and increased significantly after the BP exercise compared to all other measures ($p < 0.01$). The concentration of cortisol was also significantly higher 30 min post-exercise compared to baseline values in the 2/0/2/0 tempo protocol ($p < 0.01$). In the 6/0/2/0 tempo protocol, the cortisol concentration after the squat and bench press was significantly higher compared to baseline values and compared to 30 min post-exercise ($p < 0.01$; Figure 4). Besides the baseline, all cortisol values were higher in the 2/0/2/0 tempo compared to the 6/0/2/0 exercise protocol ($p < 0.01$; Figure 4, Tables 2 and 3).

Significant differences between GH concentrations were found during and after the training sessions ($F_{3,78}$ = 27, $p < 0.001$, $\eta^2 = 0.51$) and different tempo exercise protocols ($F_{3,78}$ = 3.8, $p < 0.042$, $\eta^2 = 0.10$). The post hoc tests showed that GH concentration was significantly higher after the squat compared to all other measures ($p < 0.01$), significantly increased after the bench press exercise compared to baseline and compared to 30 min post-exercise ($p < 0.01$), and increased 30 min into recovery compared to the baseline in both protocols ($p < 0.01$). Besides baseline, all GH values were significantly higher in the 2/0/2/0 exercise protocol compared to the 6/0/2/0 protocol (Figure 4, Tables 2 and 3).

Significant differences between IGF-1 concentrations were found during and after the training sessions ($F_{3,78}$ = 5.5, $p = 0.002$, $\eta^2 = 0.17$). The post hoc test showed a significant increases of IGF-1 concentration after the squats compared to all other measures in both exercise protocols ($p < 0.01$) and a significant increase after the bench press exercise compared to baseline and compared to 30 min of recovery in the 2/0/2/0 tempo protocol ($p < 0.01$). The IGF-1 concentration after the squat and bench press exercise was significantly higher following the 2/0/2/0 compared to the 6/0/2/0 movement tempo protocol (Figure 4, Tables 2 and 3).

Significant differences between testosterone concentrations were found during and after exercise ($F_{3,78} = 56$, $p < 0.001$, $\eta^2 = 0.68$). The post hoc test showed significant increases in testosterone concentration after the squat and bench press exercises compared to pre-squat and 30 min into recovery in both protocols ($p < 0.01$; Figure 4, Tables 2 and 3).

Particular hormonal responses were different among the athletes, however with similar trends (Figure 5).

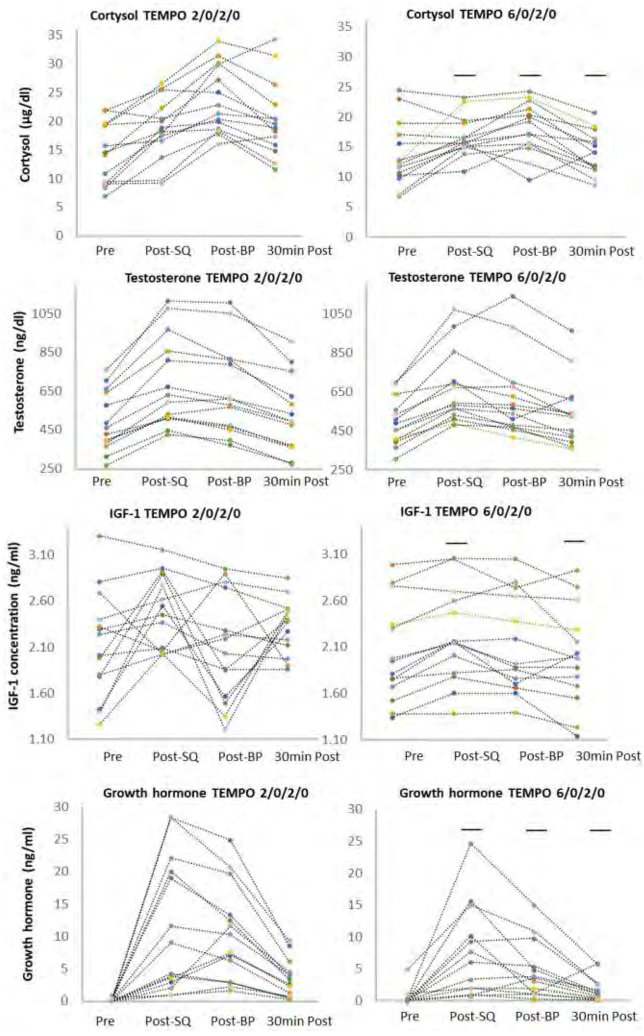

Figure 5. Physiological responses of cortisol, growth hormone, testosterone, and IGF-1 during the squat and bench press exercise protocols for fast (2/0/2/0) and medium (6/0/2/0) movement tempo. GH = growth hormone, IGF-1 = insulin-like growth factor. The dash line indicates the significant difference between TEMPO protocols, lower values for 6/0/2/0.

4. Discussion

The main finding of this study was that ice-hockey players had similar testosterone responses after medium and fast eccentric movement tempo during resistance exercise. However, fast eccentric tempo induced higher cortisol, IGF-1, and growth hormone responses compared to the medium tempo. Therefore, this result justifies the use of fast eccentric tempo during resistance training programs in ice-hockey players to induce a higher post-exercise increase in hormonal responses, which may be an important factor influencing muscular strength and hypertrophy adaptive changes. However, the fast movement tempo exercise protocol elicited greater muscular fatigue, which should be taken into account when programming the recovery time during particular training micro-cycles.

The results of the presented study are contradictive with previous studies showing that a medium movement tempo was more effective in inducing higher acute hormonal responses following resistance exercise [8,13,16], as well as contradictive with studies which do not show differences in acute hormonal responses between different movement tempos [14,37,38]. However, the differences between the results of the presented experiment and other studies can be related to the specificity of the study participants. Ice-hockey players are well adapted to isometric and controlled eccentric loading in the squat position below 90°of knee flexion [10,24,28], therefore increasing the duration of the eccentric part of an resistance exercise does not provide additional stimulus, as reported in other studies [13,16]. The factor of adaptation to isometric lower limb loading is pronounced during the ice-hockey season with every day on-ice training. Additionally, it should be noted that this research procedure assumes conducting a 4-week familiarization session with the exercises performed with different movement tempo to restrict possible learning effects. According to the authors' knowledge, there were no previous studies related to the impact of different movement tempos on acute hormonal and metabolic responses in participants or athletes habituated to resistance exercise performed with medium eccentric movement tempo, which also could have an impact on the obtained results. The longer movement duration increases TUT during resistance exercise [32], which is usually the main factor inducing higher post-exercise hormonal changes in medium or slow movement tempo. Such increases of TUT could be a stimulating factor especially when medium movement tempo is used as an alternative method of resistance training. However, when such training intervention (with longer maximal TUT) is performed commonly in training routines, it may no longer be sufficient to stimulate acute hormonal responses. Furthermore the Pareja-Blanco et al. [39] suggested that greater force generation would be required to perform faster movements, which would result in greater recruitment of muscle fibers with higher glycolytic potential despite the longer TUT during training with medium movement tempo. It has been speculated that local accumulation of anaerobic energy metabolites, such as lactate, stimulate the secretion of anabolic hormones [40] which may also be the basis for explaining the obtained results. Moreover, as it was observed in our study, the fast exercise movement tempo protocol elicited greater muscular fatigue, which may be explained by higher total concentric work performed during the exercise with fast movement tempo (greater number of performed repetitions). Thus, increasing the TUT as it was observed for the medium movement tempo does not provide more intense acute post-exercise hormonal responses in subjects habituated to medium or slow movement tempo, yet a greater number of repetitions during the concentric phase of the movement does. Our results seem to be contradictive with previous studies showing that a longer eccentric phase increases the hormonal response [8,13], however, there is always the question of whether TUT or the number of performed repetitions are superior in eliciting a greater endocrine response. Since cortisol responses gradually increased after the squat and bench press exercises in both protocols, we can assume that both protocols were sufficiently exhausting, yet the hockey players responded more intensively to the training protocol with a higher number of performed repetitions and a faster movement tempo (2/0/2/0). Although the testosterone and GH were significantly elevated after the squat, their increase after the bench press was lower. This may be explained by the fact that the anabolic response to exercise is partially related to exercise volume and may even decrease along with fatigue. In this case, the bench press provided a lower lifted workload and was performed after a more exhaustive squat exercise. However, a similar response in testosterone and overall hormonal secretion shows that both exercise tempo protocols provide a positive anabolic stimuli, which can be beneficial for ice-hockey players. Therefore, we cannot conclude that medium movement tempo is ineffective, but less effective in inducing endocrine responses than a fast eccentric movement tempo.

According to the results of our study, it can be concluded that resistance exercise sessions targeted at recovery (anabolic responses) should be performed in ice-hockey players with a fast eccentric movement tempo. This is especially relevant if the athletes can maintain proper exercise technique throughout the whole training session. The application of the fast tempo of movement should be performed for non-specific exercises [2,3] which should not overlap with specific ones. On the other hand, medium movement tempo during resistance exercises could be applied if players have problems with exercise technique or during hockey-specific exercises [5]; however, this training will have a smaller effect on GH and IGF-1 responses than fast movement tempo and will provide a smaller anabolic (regenerative) response. In general, training with prolonged eccentric tempo is very specific, and induces most of the adaptive changes through increased time under tension. On the other hand fast tempo of movement during resistance exercises induce their metabolic effect through a higher number of performed repetitions.

The presented training protocol may be regarded as non-specific for ice-hockey players since two main complex exercises were used in their bilateral basics. During the season, a high dominance of specific loading may elicit over-use injuries, and therefore more general exercises should be used to balance the specific ones. Thus, it is essential that exercises like bilateral squats or the bench press provide anabolic responses without over-stressing the same ligaments and muscles used during hockey-specific movements like hip abduction/adduction [28,41,42]. Therefore, the presented resistance exercise protocols should be used for ice-hockey as non-specific loading aimed to provide an anabolic stimuli.

This study's principal limitation is the cross-sectional evaluation instead of an intervention study, which was compensated by the participants' high familiarization. Another important aspect is the data sampling until 30 min post-exercise, while the optimal data collection should also be performed 24 h post exercise. The analyzed hormones have a liner response and the efflux into the bloodstream could be maintained for 24 h post exercise, which requires further research.

5. Conclusions

A fast eccentric tempo seems to be more useful in eliciting a significant post-exercise hormonal stimulus compared to medium eccentric movement tempo. Hockey players respond more intensively to a higher number of repetitions than to longer time under tension in non-specific resistance exercises. Therefore, squats and the bench press exercises with a fast eccentric tempo should be used in ice-hockey during periods of non-specific resistance training programs. Considering that squats and/or bench press exercises are routinely used as interventions in numerous studies, the presented results and practical implications can be transferred to other sports disciplines.

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Data Availability Statement: The dataset used and/or analyzed during the current study is available from the corresponding author in response to a reasonable request. Due to patient's data, privacy data are not made available publicly.

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7 PODSUMOWANIE

Analiza i ocena wpływu czasu trwania powtórzenia determinowana przez wartość TUT wykazała istotny wpływ na całkowitą liczbę powtórzeń w serii oraz w całym ćwiczeniu, poziom generowanej mocy i prędkość sztangi, a także na poziom reakcji metabolicznych i hormonalnych.

Ponadto przedstawiony cykl badań wykazał, że w ocenie objętości wysiłku oprócz powszechnie stosowanej liczby wykonanych powtórzeń należy także określać czas trwania napięcia mięśniowego. Badania dowiodły, że dłuższy czas trwania ekscentrycznej fazy ruchu powoduje obniżenie wartości maksymalnej siły mięśniowej oraz poziomu generowanej mocy mięśniowej w fazie koncentrycznej. Ponadto dłuższy czas trwania fazy ekscentrycznej nieznacznie wpływa na powysiłkowe zmiany wartości GH i IGF-1, w przeciwieństwie do krótkiej fazy ekscentrycznej (6/0/2/0 vs. 2/0/2/0). Jednakże poziom powysiłkowych zamian metabolicznych i hormonalnych są zależne od faktu, czy uczestnik posiada doświadczenie w treningu oporowym z wykorzystaniem różnego tempa powtórzenia. Istotne wydłużenie maksymalnego czasu wysiłku podczas zastosowania dłuższego czasu trwania powtórzenia powoduje konieczność zastosowania niższej wartości obciążenia zewnętrznego, co może być korzystne w treningu osób młodych, starszych oraz osób kontuzjowanych, którzy z różnych względów nie mogą stosować wysokich wartości obciążeń zewnętrznych. Co więcej, dłuższy czas trwania powtórzenia podczas ćwiczeń oporowych pozwala na wykonywanie wysiłku o wyższej wartości TUT, co może mieć szczególne korzystne znaczenie w kształtowaniu wytrzymałości siłowej. Ponadto prowadzone badania nie wykazały istotnych różnic w zakresie TUT i liczby powtórzeń między szerokościami chwytu sztangi (WGBP vs. CGBP) podczas wyciskania leżąc.

Chociaż wpływ czasu trwania powtórzenia oraz wartości TUT w odniesieniu do adaptacji nerwowo-mięśniowych nie jest szeroko zbadany, wydaje się, że na podstawie wartości TUT można w precyzyjny sposób określić optymalny zakres wysiłku w rozwoju siły i hipertrofii mięśniowej. Chociaż istnieją badania naukowe, w których zastosowano kontrolowany czas trwania powtórzenia i jego wpływ na proces zmian adaptacyjnych (Bird i wsp., 2005; Neils i wsp., 2005; Westcott i wsp., 2001), to obecnie jedynie jedna naukowa praca wskazuje optymalne wartości TUT dla rozwoju hipertrofii, siły maksymalnej, czy wytrzymałości mięśniowej (Wilk i wsp., 2021).

Wyniki badania wydają się sprzeczne z wcześniejszymi doniesieniami naukowymi, w których wykazano, że wydłużenie czasu trwania fazy ekscentrycznej zwiększa odpowiedź hormonalną (Wilk i wsp., 2018, 2020) oraz z badaniami, w których nie wykazano różnic w odpowiedzi hormonalnej między protokołami z różnym czasem trwania powtórzenia (Headley i wsp., 2011; Smilios i wsp., 2014; Wilk i wsp., 2021). w badaniu krótki czas trwania fazy ekscentrycznej wywołał wyższy poziom odpowiedzi kortyzolu, IGF-1 oraz GH, w porównaniu do długiego czasu (2s vs. 6s). Wynik ten uzasadnia planowanie i stosowanie krótkiego czasu trwania fazy ekscentrycznej w celu wywołania wyższych powysiłkowych wartości hormonalnych, które mogą być ważnym czynnikiem wpływającym na kierunek zmian adaptacyjnych pod kątem hipertrofii i siły mięśniowej. Jednakże najnowsze wyniki badań (Villanueva i wsp., 2021) sugerują, że nie tylko same wartości czasu trwania wysiłku w poszczególnych fazach ruchu mogą mieć znaczenie, ale także stosunek czasu trwania pracy w fazie koncentrycznej do czasu trwania pracy w fazie ekscentrycznej. Dlatego też badania dotyczące zmiennego tempa powtórzenia nadal wymagają dalszej eksploracji.

Analiza i wyniki przeprowadzonych badań wskazują, że czas trwania powtórzenia jest ważną składową w aspekcie procesu treningu oporowego mającą wpływ na wartość objętości wysiłku, poziom siły maksymalnej i mocy mięśniowej oraz powysiłkowych wartości endokrynnych. Ponadto wartość TUT wydaje się dokładniejszym wskaźnikiem sumarycznej pracy wykonanej podczas jednostki treningowej, w porównaniu z powszechnie stosowanymi metodami. Biorąc pod uwagę omówione wyniki badań, należy wskazać, że czas trwania powtórzenia, jako dodatkowa zmienna treningowa w ćwiczeniu oporowym, powinien być kontrolowany i zaplanowany w procesie programowania treningu. Ponadto wpływ zmiennego tempa powtórzenia na bezpośrednie i długofalowe zmiany adaptacyjne może być zależny od doświadczenia w stosowaniu zmiennego tempa powtórzenia, co jest przełomowym wnioskiem z przeprowadzonego cyklu badań.

8 STRESZCZENIE

Przedstawione w osiągnięciu naukowym cztery prace empiryczne zmierzały do oceny wpływu czasu trwania powtórzenia w ćwiczeniach oporowych na bezpośredni efekt treningowy. Przeprowadzono cztery niezależne eksperymenty, w których dokonano analizy i oceny wpływu zmiennego czasu trwania powtórzenia na objętość wysiłku, wartość maksymalną siły mięśniowej, poziom mocy mięśniowej oraz zakres powysiłkowych reakcji endokrynnych.

Głównym celem pierwszego badania było ustalenie czy poziom doświadczenia w treningu oporowym ma istotny wpływ na różnice w objętości wysiłku przy zastosowaniu zmiennego czasu trwania powtórzenia (2/0/2/0, 5/0/3/0, 6/0/4/0). Wyniki badań wykazały, że poziom doświadczenia w treningu oporowym, a przede wszystkim czas trwania powtórzenia ma znaczący wpływ na objętość wysiłku zarówno pod względem wartości czasu napięcia mięśniowego (TUT – time under tension), jak i liczby powtórzeń (REP – repetition). w drugim badaniu analizie poddano wpływ wyciskania sztangi leżąc z szerokim i wąskim chwytem sztangi na poziom mocy mięśniowej i prędkości sztangi mierzonej w ruchu koncentrycznym także z zastosowaniem zmiennego czasu trwania fazy ekscentrycznej ruchu (6/0/X/0 vs. 2/0/X/0). Badania wykazały, że zmiana czasu trwania fazy ekscentrycznej ruchu istotnie wpływa na moc mięśniową i prędkość sztangi podczas wyciskania leżąc, jednak nie stwierdzono istotnych różnic wartości mocy mięśniowej pomiędzy szerokim, a wąskim chwytem sztangi. Trzecie badanie dotyczyło oceny wpływu czasu trwania ekscentrycznej fazy ruchu na wynik testu siły maksymalnej 1-RM podczas wyciskania sztangi leżąc. Głównym wnioskiem trzeciego badania jest fakt, że dłuższy czas trwania ekscentrycznej fazy ruchu powoduje obniżenie wartości maksymalnego obciążenia zewnętrznego w teście 1-RM, co ma szczególnie istotne znaczenie w ocenie poziomu siły mięśniowej w warunkach nielaboratoryjnych. w ostatnim badaniu analizie poddano wpływ zmiany czasu trwania powtórzenia na powysiłkowe reakcje hormonalne wśród doświadczonych zawodników hokeja na lodzie. Wyniki badań wykazały, że czas trwania ekscentrycznej fazy ruchu wpływa na wartość wykonanej liczby powtórzeń oraz wartość TUT zarówno w podczas wyciskania sztangi leżąc, jak i podczas przysiadów ze sztangą. Ponadto badania wykazały, że powysiłkowe zmiany stężenia IGF-1, GH oraz kortyzolu były

wyższe podczas protokołu, w którym wykorzystano krótszy czas trwania fazy ekscentrycznej (2s), w porównaniu z dłuższym czasem trwania fazy ekscentrycznej (6s).

Analiza i wyniki przeprowadzonych badań wskazują, że czas trwania powtórzenia jest istotnym elementem planowania i programowania treningu oporowego, mający szczególny wpływ na objętość wysiłku, poziom siły maksymalnej i mocy mięśniowej oraz powysiłkowych zmiany stężenia hormonów. Ponadto wartość TUT wydaje się dokładniejszym wskaźnikiem objętości wysiłku, w porównaniu z wartością liczby wykonanych powtórzeń.

9 SUMMARY

The analysis and evaluation of the effect of the duration of the repetition determined by the TUT value showed a significant effect on the total number of repetitions in the set and throughout the exercise, the level of power output generated, as well as hormonal reactions.

Moreover, the presented series of tests showed that in the assessment of the exercise volume, in addition to the commonly used number of repetitions, the duration of time under tension should also be determined. Studies have shown that a longer duration of the eccentric phase of movement reduces the value of the maximum muscle strength and the level of power output generated in the concentric phase. Moreover, the longer duration of the eccentric phase slightly affects the post-exercise changes in GH and IGF-1 values, in contrast to the short eccentric phase (6/0/2/0 vs. 2/0/2/0). a significant extension of the maximum exercise time when using a longer duration of the repetition causes the necessity to use a lower value of the external load, which may be beneficial in training young, elderly and injured people who, for various reasons, cannot use high values of external loads. Moreover, a longer repetition duration during resistance exercises allows for an effort with a higher TUT value, which may be of particular benefit in shaping strength endurance. Moreover, the conducted research did not show significant differences in terms of TUT and the number of repetitions between the bar grip widths (WGBP vs. CGBP) during bench press.

Although the effect of the duration of the repetition and the TUT value in relation to neuromuscular adaptation is not widely studied, it seems that from the TUT value it is possible to precisely determine the optimal range of effort for the development of muscle strength and hypertrophy. Although there are scientific studies that have used a controlled repetition duration and its impact on the process of adaptive change (Bird et al., 2005; Neils et al., 2005; Westcott et al., 2001), currently only one scientific study indicates the optimal TUT values for the development of hypertrophy, maximum strength or muscle endurance (Wilk et al., 2021). The results of the study seem to contradict previous scientific reports, which showed that prolonging the duration of the eccentric phase increases the hormonal response (Wilk et al., 2018, 2020) and with studies that showed no differences in the hormonal response between protocols with different repeat durations (Headley et al., 2011; Smilios et al., 2014; Wilk et al., 2021). In study, the short duration of the eccentric phase induced a higher level of cortisol, IGF-1 and GH responses compared to the long duration (2s vs. 6s). This result justifies the planning and use of a short duration of the eccentric phase in order to induce higher post-exercise hormonal values, which may be an important factor influencing the direction of adaptive changes in terms of muscle hypertrophy and strength. However, the latest research results (Villanueva et al., 2021) suggest that not only the values of exercise duration in particular phases of movement may be important, but also the ratio of the duration of work in the concentric phase to the duration of work in the eccentric phase.

The analysis and results of the conducted research show that the duration of the repetition is an important component in the aspect of the resistance training process, affecting the value of the exercise volume, the level of maximum strength, power output and bar velocity as well as post-exercise endocrine values. Moreover, the TUT value seems to be a more accurate indicator of the total work done during the training unit, compared to the commonly used methods. Taking into account the discussed research results, it should be pointed out that the duration of the repetition, as an additional training variable in resistance exercise, should be controlled and planned in the training programming process. In addition, the impact of variable repetition rate on direct and long-term adaptive changes may be dependent on experience in the use of variable repetition rate, which is a landmark conclusion from the dysertation.

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