Tese de Doutorado

EFEITOS AGUDOS E CRÔNICOS DO EXERCÍCIO FÍSICO SOBRE PARÂMETROS CARDIOVASCULARES E NEUROMUSCULARES EM HOMENS IDOSOS: RESULTADOS DE DOIS ENSAIOS CLÍNICOS RANDOMIZADOS

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Tese submetida como requisito para obtenção do grau de doutor ao Programa de Pós-Graduação em Ciências da Saúde, Área de Concentração: Cardiologia e Ciências Cardiovasculares, da Universidade Federal do Rio Grande do Sul.

Porto Alegre / RS
2016

CIP - Catalogação na Publicação

Ferrari da Silva, Rodrigo
EFEITOS AGUDOS E CRÔNICOS DO EXERCÍCIO FÍSICO SOBRE PARÂMETROS CARDIOVASCULARES E NEUROMUSCULARES EM HOMENS IDOSOS: RESULTADOS DE DOIS ENSAIOS CLÍNICOS RANDOMIZADOS / Rodrigo Ferrari da Silva. -- 2016.
74 f.

Orientador: Sandra Cristina Costa Fuchs.

Tese (Doutorado) -- Universidade Federal do Rio Grande do Sul, Faculdade de Medicina, Programa de Pós-Graduação em Ciências da Saúde: Cardiologia e Ciências Cardiovasculares, Porto Alegre, BR-RS, 2016.

1. Exercício Físico. 2. Envelhecimento. 3. Hipertensão. 4. Treinamento concorrente. I. Cristina Costa Fuchs, Sandra, orient. II. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

AGRADECIMENTOS

Primeiramente, gostaria de agradecer minha orientadora, Profa. Dra. Sandra Costa Fuchs, pela incentivo na busca de oportunidades profissionais, disponibilidade para ajudar sempre que necessário e alta qualidade na orientação da minha tese de doutorado.

Ao Prof. Dr. Daniel Umpierre de Moraes que, além de um amigo pessoal, atuou como co-orientador desde meu primeiro dia no Laboratório de Fisiopatologia do Exercício (LAFIEX), estando sempre disponível e interessado em ajudar em todas as questões referentes ao meu doutorado.

Ao Dr. Jorge Pinto Ribeiro (em memória), por ter aberto as portas e dado a oportunidade de realização do doutorado no LAFIEX, e por ser exemplo de profissional a ser seguido por todos os pesquisadores da área da saúde e do exercício físico.

Ao Prof. Dr. Hirofumi Tanaka e a *University of Texas at Austin* pela oportunidade de estudo e aperfeiçoamento ao longo de 6 meses.

Aos demais Professores e pesquisadores que fizeram parte da minha trajetória, me ajudando, incentivando e servindo de inspiração para a busca da excelência profissional.

A Sirlei, do PPG Cardiologia, pela amizade e ajuda sempre ao longo do doutorado.

Ao Hospital de Clínicas de Porto Alegre, Escola de Educação Física e a Universidade Federal do Rio Grande do Sul pelas oportunidades de aprendizagem ao longo desses anos e pelo ensino de qualidade.

Aos integrantes do LAFIEX e GPAT, sempre dispostos a colaborar nas questões acadêmicas. Um agradecimento especial a Jordana Pires, Matheus Conceição, Lucas Santos e Guilherme Vogel pela grande ajuda ao longo das coletas de dados da tese.

Por fim, um agradecimento muito especial à minha família. Aos meus pais Nauro e Dora, que dedicaram tempo, amor e carinho na minha formação pessoal e profissional, sendo meus maiores e melhores exemplos na vida. Aos meus irmãos Guilherme e Gabriel, pela amizade, disponibilidade e parceria de todas as horas. Aos demais familiares, especialmente aqueles incentivadores da profissão que escolhi exercer e sempre me incentivaram a ir atrás dos meus sonhos. Além deles, agradeço a pessoa que escolhi pra dividir todos os momentos comigo, Julia, só tu sabes o que passei pra chegar neste momento, teu amor, carinho, parceria e sensibilidade foram fundamentais para que eu pudesse finalizar este ciclo acadêmico.

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RESUMO

Estudo 1:

Objetivos: Avaliar os efeitos do número de sessões semanais de treinamento concorrente (TC) nas adaptações cardiovasculares e neuromusculares de homens idosos treinados. **Métodos:** 24 homens idosos, previamente treinados, foram randomizados em 2 grupos diferentes na frequência semanal (2/sem ou 3/sem) e realizaram TC ao longo de 10 semanas. Antes e após o treinamento, força máxima, potência, massa muscular, consumo de oxigênio, pressão arterial e hiperemia reativa foram avaliadas. **Resultados:** Foram encontrados aumentos semelhantes em ambos os grupos no VO_{2max} e em todas as variáveis neuromusculares. Não houve diferença ao final do treinamento na PA e hiperemia reativa. **Conclusão:** O treinamento concorrente realizado 2 x semana é um modelo de exercício eficiente para o desenvolvimento de força, potência, massa muscular e consumo de oxigênio em idosos treinados.

Estudo 2:

Objetivos: Comparar a variação da pressão arterial (PA) pós-exercício em indivíduos idosos hipertensos submetidos a exercício aeróbio, exercício concorrente ou sessão controle. **Métodos:** 20 homens idosos hipertensos foram submetidos, em ordem randomizada, a três intervenções com 45 min de duração: exercício aeróbio (EA), exercício concorrente (EC) e sessão controle (C). A PA foi avaliada após cada intervenção por 1h dentro do laboratório e ao longo de 24h através da MAPA. **Resultados:** Redução significativa na PA sistólica e diastólica na primeira hora após o EA e EC, quando comparado a C. Redução significativa na PA diastólica diruna após o EA, quando comparado a C. **Conclusão:** Ambos os exercícios reduziram a PA em condições laboratoriais, porém o exercício aeróbio sustentou essa redução por um período mais prolongado na PA diastólica em homens idosos hipertensos.

LISTA DE ABREVIATURAS E SIGLAS

EF – exercício físico

EA – exercício aeróbio

ER – exercício resistido ou de força

EC – exercício concorrente

HAS – hipertensão arterial sistêmica

DCVs – doenças cardiovasculares

HPE – hipotensão pós-exercício

PA – pressão arterial

PAD – pressão arterial diastólica

PAS – pressão arterial sistólica

RVP – resistência vascular periférica

DC – débito cardíaco

1.INTRODUÇÃO

A população idosa (i.e., acima de 60 anos), que atualmente representa 12% da população mundial, aumentará para 22% até 2050, o que representa quase o dobro de indivíduos idosos (1). Globalmente, o rápido envelhecimento populacional é explicado por aumento da expectativa de vida e redução das taxas de natalidade (2). Contudo, especialmente nos países de renda média e baixa, políticas públicas e serviços primários de atenção à saúde ainda apresentam pouca eficiência no manejo dos processos deletérios do envelhecimento (3).

O envelhecimento biológico está associado ao declínio de diferentes sistemas fisiológicos, entre eles o sistema neuromuscular, através da perda de força, potência e massa muscular (4), e o sistema cardiorrespiratório, através da redução da capacidade máxima de utilização do oxigênio (VO_{2max}) (5). Essas reduções estão diretamente relacionadas à perda da mobilidade dos indivíduos, que afeta a independência e a qualidade de vida dessa população (6). Ainda, o processo de envelhecimento é considerado um fator de risco para o desenvolvimento e a progressão da maioria das doenças crônicas degenerativas (7).

A busca do envelhecimento saudável não pressupõe ausência de doenças, mas representa o processo que permite que pessoas mais velhas continuem realizando suas atividades com independência. Uma das dificuldades para desenvolver e implementar estratégias de promoção de saúde nessa população é a grande variabilidade nas características dos indivíduos mais velhos, fazendo com que não exista um idoso típico (3). Pode-se classificar um idosos de maneira cronológica (i.e., idade dos indivíduos) ou através de sua capacidade funcional, que reflete a capacidade dos indivíduos idosos de realizar atividades de vida diária (AVD's) com segurança e independência e sem fadiga excessiva (8).

A prática regular de exercícios físicos (EF) é uma estratégia importante no combate aos efeitos deletérios do envelhecimento. Incrementos no VO_{2max} (9), na massa muscular (10), na força (11) e na potência muscular (12) são algumas das alterações positivas que o EF proporciona. Essas mudanças permitem que indivíduos idosos realizem tarefas como subir escadas, deslocar-se de um lugar para outro sem necessidade de paradas, sentar ou levantar e equilibrar-se com maior independência (8, 13).

Um ensaio clínico randomizado incluindo grande número de participantes, publicado recentemente (14), ratificou a importância do EF para a população idosa. Ao avaliarem-se os efeitos do exercício físico sobre a redução da incapacidade funcional em indivíduos idosos com limitações funcionais ao longo de 2,6 anos, resultados do *LIFE study* demonstraram que o EF estruturado e orientado, quando comparado a uma intervenção predominantemente educativa, foi capaz de reduzir em 18% a incapacidade funcional (i.e., incapacidade de caminhar 400 m com independência).

Apesar dos resultados positivos supracitados, muitos dos potenciais benefícios que o EF pode trazer para a população idosa ainda não foram confirmados por pesquisas bem delineadas. Tal fato torna fundamental a realização de novos estudos sobre EF e envelhecimento.

2. REVISÃO DE LITERATURA

2.1 *Exercício físico no envelhecimento*

Diferentes estratégias são desenvolvidas na busca do envelhecimento saudável. Destaca-se, dentre elas, a prática regular de EF, excelente opção não farmacológica para a promoção da saúde e qualidade de vida do idoso (7). Os benefícios da prática do EF na redução do risco de desenvolver doenças crônicas e de mortalidade (15), bem como no aumento da capacidade funcional (16), tornam essencial a realização dessa estratégia na busca do envelhecimento saudável.

Uma revisão recente apresentando os benefícios da prática do EF como primeira linha de tratamento de diversas doenças crônicas (17) sugeriu a necessidade urgente dos sistemas de saúde criarem infraestrutura para oferecer EF supervisionado para o tratamento de doenças cardiovasculares (DCVs), metabólicas, psiquiátricas, músculo esqueléticas, entre outras.

Diferentes pesquisas detectaram associação inversa entre a capacidade cardiorrespiratória (i.e., consumo máximo de oxigênio - VO_{2max}) e o risco de morte (18-20). Um estudo de coorte, acompanhou 4.631 homens veteranos hipertensos, demonstrou que maior capacidade cardiorrespiratória está associada a menor risco de mortalidade, mesmo naqueles indivíduos com outros fatores de risco associados (i.e., diabetes mellitus, índice de massa corporal, entre outros) (18). Outra variável que também associa-se inversamente com o risco de morte por qualquer causa é a força muscular. Em homens, valores elevados de força muscular reduziram em 60% o risco de morte, quando comparado com homens com menor força muscular (21).

Na população idosa, a efetividade do EF no aumento do VO_{2max} (9), da massa muscular (11), força (10) e potência muscular (22), amplamente descritas na literatura, permite a realização de tarefas como subir escadas, deslocar-se de um lugar para outro sem necessidade de paradas, sentar ou levantar e equilibrar-se com maior independência (13).

Embora os benefícios supracitados do EF em indivíduos idosos sejam cada vez mais difundidos na comunidade científica, na mídia e alguns programas de saúde pública, ainda existe resistência muito grande por parte dessa população em aderir a programas de EF. Os principais resultados de uma revisão sistemática sobre adesão de indivíduos idosos a programas de EF sugerem maior aderência quando o programa de exercício é supervisionado (23). Esse resultado permite destacar o papel do educador físico em intervenções de EF na população idosa. Outro fator apontado para baixa aderência ao EF é o tempo gasto para que se atinjam os objetivos propostos (24), salientando a necessidade de desenvolverem-se programas de EF mais rápidos e eficientes para seus praticantes.

2.2 *Modelos de exercício físico para idosos*

A partir dos diferentes benefícios associados ao EF em indivíduos idosos, muitas pesquisas foram desenvolvidas na tentativa de apontar quais são as melhores estratégias para elaborar programas de exercícios para essa população. Quando o principal objetivo é a manutenção e o aumento da massa muscular, bem como o incremento da força, potência e da resistência muscular, exercícios resistidos (ER) parecem ser os mais adequados (25, 26). Já para incrementos no VO_{2max} e redução de risco de desenvolver doenças cardiovasculares, a utilização de exercícios aeróbios (EA) é apontada como a estratégia mais efetiva (27, 28).

Considerando os diferentes benefícios dos modelos de EF supracitados, um programa composto por exercícios aeróbios associados a exercícios de força torna-se uma estratégia essencial para promoção da saúde, prevenção e tratamento de doenças na população idosa (22, 29). É denominado treinamento concorrente (TC) a realização simultânea de EA e ER em um mesmo programa de EF (30).

A partir do final da década de 90, diversos estudos vêm sendo realizados para avaliar diferentes benefícios do TC na população idosa (Tabela 1). Um cuidado ao realizar simultaneamente essas duas formas de exercício é a possível incompatibilidade nas adaptações do sistema neuromuscular, ou seja, não é possível obterem-se os mesmos ganhos de um treinamento de força (TF) isolado quando acrescentamos o treinamento aeróbio (TA) no programa (31, 32). Essa associação pode atenuar ganhos de força máxima (32), potência (33) e hipertrofia muscular (34) nos indivíduos que utilizam essa estratégia de treinamento. Embora a grande maioria dos estudos realizados (11, 29, 35, 36) não tenham encontrado essa interferência nas adaptações neuromusculares ao realizarem o TC em idosos, Cadore et al. (32) encontraram menores ganhos de força máxima em idosos submetidos a um programa de TC quando comparados aqueles que realizaram apenas o TF. Convém salientar que nessa população, pela necessidade de níveis suficientes de força e potência para a realização das AVD’s com independência (37), é fundamental que os incrementos de força e potência sejam otimizados.

Tabela 1: Resumo dos estudos sobre Treinamento Concorrente em idosos, com ênfase nos resultados de força de membros inferiores e capacidade cardiorrespiratória.

Referência (ano)	Grupos (Participantes por grupo)/ Idade (média)	Gênero/ Nível de Treinamento	Modalidade: Volume/ Intensidade	Frequência; Duração	Resultados principais
Ferketich et al. (1998)	C (n=6)/ 69 anos A (n=8)/ 69 anos A+F (n=7)/ 67 anos	Mulheres/ Não treinadas	Força: 2 x 12-15rep./ 80% de 10RM Aeróbio (cicloergômetro): 30 min/ 70-80% VO_{2max}	3x/semana 12 semanas	10RM: ↑111% (A+F)/ 43% (A) VO_{2max}: ↑29% (A+F)/ 25% (A)
Wood et al. (2001)	F (n=11)/ 69 anos A (n=10)/ 69 anos A+F (n=9)/ 66 anos C (n=6)/ 68 anos	Homens e Mulheres/ Não treinados	Força: 2 x 8-12RM Aeróbio (esteira/ cicloergômetro): 45 min/ 60-70% $FC_{RESERVA}$	3x/semana; 12 semanas	5RM: ↑44% (F)/ 38% (A+F)/ 24% (A) Tempo p/ caminhar 800 metros: ↓9% (A)/ 8% (F)/ 8% (A+F)
Izquierdo et al. (2004)	F (n=11)/ 65 anos A (n=10)/ 68 anos F+A (n=10)/ 66 anos	Homens/Não treinados	Força: 3-5 x 15-5rep./ 50-80%1RM Aeróbio (cicloergômetro): 30-40 min/ 70-90% $FC_{máxima}$	2x/semana; 16 semanas	1RM:↑41% (F)/ 38% (F+A)/ 11% (A) Potência máxima em cicloergômetro: ↑16% (A)/ 18% (F+A)/ 10% (F)
Karavirta et al. (2009)	F (n=25)/ 56 anos A (n=25)/ 54 anos A+F (n=30)/ 56 anos C (n=16)/ 55 anos	Homens/ Não treinados	Força: 2-4 x 20-5rep./ 40-85%1RM Aeróbio (cicloergômetro): 30-90 min/ diferentes % do VO_{2max}	2x/semana; 21 semanas	1RM:↑21% (F)/ 22% (F+A)/ 7% (A)/ 5% (C) VO_{2max}: ↑12% (A)/ 10% (F+A)

Cadore et al. (2010)	F (n=11)/ 65 anos A (n=10)/ 68 anos F+A (n=10)/ 66 anos	Homens/Não treinados	Força: 2-3 x 20-6RM Aeróbio (cicloergômetro): 20-30 min/ 80-100% FC_{limiar}	3x/semana; 12 semanas	1RM:↑67% (F)/ 41% (F+A)/ 25% (A) VO_{2max}:↑21% (A)/ 20% (F+A)
Cadore et al. (2012)	F+A (n=13)/ 64 anos A+F (n=13)/ 64 anos	Homens/Não treinados	Força: 2-3 x 20-6RM Aeróbio (cicloergômetro): 20-30 min/ 80-100% FC_{limiar}	3x/semana; 12 semanas	1RM:↑34% (F+A)/ 21% (A+F) VO_{2max}:↑ 7% (A+F)/ 8% (F+A)
Wilhelm et al. (2014)	C (n=13)/ 65 anos A+F (n=11)/ 63 anos F+A (n=12)/ 67 anos	Homens/Não treinados	Força: 2-3 x 18-8RM Aeróbio (cicloergômetro): 20-40 min/ 85-95% FC_{limiar}	2x/semana; 12 semanas	1RM:↑18% (A+F)/ 14% (F+A) VO_{2max}:↑ 6% (A+F)/ 8% (F+A)/ 2% (C)
Kanitz et al. (2015)	F+A (n=16)/ 64 anos A (n=18)/ 66 anos	Homens/Não treinados	Força: 2-4 séries/ 20-15s Aeróbio: 30 min/ 85-100% FC_{limiar}	3x/semana; 12 semanas	1RM:↑9% (A)/ 6% (F+A) VO_{2max}: ↑41% (A)/ 17% (F+A)
Pinto et al. (2015)	F+A (n=10)/ 57 anos A+F (n=11)/ 57 anos	Mulheres/ Não treinadas	Força: 3-6 séries/ 20-10s Aeróbio: 18-36 min/ 85-100% FC_{limiar}	2x/semana; 12 semanas	1RM:↑33% (F+A)/ 11% (A+F) VO_{2max}: Não significativo

RM: repetições máximas; 1RM: Uma repetição máxima; VO2max - consumo máximo de oxigênio; F - grupo que realizou apenas exercício resistido; A - grupo que realizou apenas o exercício aeróbio; C - grupo controle; F+A e A+F - grupos que realizaram simultaneamente exercício resistido e aeróbio: F+A (sessão iniciou pelo TF) e A+F (sessão iniciou pelo TA)

Os principais resultados de força máxima (i.e., 1RM) e capacidade cardiorrespiratória (i.e., VO_{2max}) encontrados em estudos sobre TC em indivíduos idosos apresentaram grande variabilidade nos percentuais de incremento dessas duas variáveis. Alterações variando entre 6-67% para 1RM e 6-41% no VO_{2max} podem ser explicadas pelo uso de diferentes populações, frequências semanais, volume e intensidade das sessões de EF utilizadas nos estudos.

Um aspecto importante associado à combinação dessas duas formas de exercício é a ordem de realização dos treinamentos dentro da sessão de treino. Programas eficientes de TC em indivíduos mais velhos devem buscar o desenvolvimento simultâneo das variáveis neuromusculares e cardiorrespiratórias, e ainda achar as melhores estruturações de treinamento para potencializar os ganhos nessa população. Interessantemente, dois estudos avaliando a influência da ordem de execução dos treinamentos dentro da sessão de TC (EA → ER ou ER → EA) demonstraram que a força muscular de idosos pode ser otimizada quando a sessão de treinamento inicia pelo ER e, posteriormente, realiza o EA (22, 38).

Embora o TC pareça ser mais eficiente para combater os diferentes processos associados ao envelhecimento e melhorar a independência física de indivíduos idosos, é possível observar que as principais informações disponíveis sobre o TC nessa população baseiam-se em estudos utilizando apenas indivíduos previamente destreinados. Esse fato impede extrapolações dos benefícios desse modelo de exercício para idosos treinados.

2.3 *Dose-resposta do exercício físico no idoso*

A organização de um programa de EF eficiente depende da correta manipulação das diferentes variáveis do treinamento, tais como: volume, intensidade, escolha de exercícios, equipamentos, entre outros (39). Dentre essas variáveis, duas merecem uma atenção especial, pois parecem ser as mais importantes e sua manipulação pode influenciar diretamente os resultados encontrados: o volume (representado no TF pelo número de séries e de repetições realizadas nessas séries e no TA pelo tempo de cada sessão e o número de vezes em que elas são realizadas por semana) e a intensidade (representada no TF pelo carga utilizada nos exercícios e no TA pelo percentual do VO_{2max}).

Uma interessante meta-análise, avaliando a dose-resposta de diferentes volumes e intensidades de TF nos incrementos de força e na performance de indivíduos idosos, aponta a dificuldade na determinação da frequência e do volume ideal de TF nessa população devido ao limitado número de estudos comparando diferentes frequências e volumes (13). Em um dos poucos estudos avaliando os efeitos de diferentes frequências semanais de TF nos ganhos de força de idosos, Taaffe et al. (40) demonstraram que os grupos que realizaram o TF 1, 2 ou 3 sessões semanais ao longo de 24 semanas incrementaram sua força máxima e a performance no teste de sentar e levantar de maneira semelhante. Já no que se refere à intensidade ideal no TF, cargas entre 60 e 80% de 1RM (cargas correspondentes a, aproximadamente, 12 e 8 RM's, respectivamente) parecem ser as mais indicadas para idosos (13).

Por outro lado, diretrizes do *American College of Sports Medicine* (7) recomendam que o TA em idosos seja realizado, pelo menos, 3 vezes por semana, com duração mínima de 20 a 30 minutos. Ainda, intensidades iguais ou superiores a 60% do VO_{2max} são necessárias para incrementos significativos no VO_{2max}. Embora incrementos na capacidade aeróbia sejam encontrados em intensidades mais baixas, altas intensidades podem gerar alterações de maior magnitude que intensidades menores. Donovan et al. (41) avaliaram a influência de diferentes intensidades de TA nas adaptações cardiorrespiratórias de homens de meia idade. Um grupo de intensidade moderada (60% do VO_{2max}) e outro grupo de alta intensidade (80% do VO_{2max}) realizaram três sessões semanais de exercício em cicloergômetro ao longo de 24 semanas. Alterações significativas foram observadas em ambos os grupos no $VO_{2máx}$, sendo esses valores significativamente superiores aos do grupo controle. Ainda, o grupo que treinou em alta intensidade obteve incrementos superiores ao grupo de intensidade moderada.

2.4 *Doenças crônicas e exercício físico*

O EF é considerado uma ferramenta de primeira linha no tratamento de dezenas de doenças crônicas (17), fato que torna fundamental que profissionais da área da saúde tenham conhecimento suficiente para aplicar intervenções que envolvam EF e sejam eficazes no combate da doença em questão.

Embora considerada uma resposta fisiológica inerente ao envelhecimento, as reduções significativas na função muscular, inicialmente observadas a partir de 40 anos e mais pronunciadas a partir dos 65-70 anos (7), podem trazer sérias consequências. Uma das principais doenças do sistema muscular associada ao processo de envelhecimento é a Sarcopenia, caracterizada pela perda de força e massa muscular que leva a redução das funções desse sistema, levando a um aumento de risco de desfechos adversos, incapacidade física, redução da qualidade de vida e aumento de mortalidade (42). O EF, especificamente os exercícios de força, vem sendo adotados como principal ferramenta para combater essa doença. Além do clássico ganho de força máxima a partir desse modelo de EF, outra variável que vêm recebendo um crescente interesse nas investigações sobre o tema é a potência muscular, apontada como importante preditor de limitações funcionais no idoso (16).

O envelhecimento está associado a disfunção endotelial e ao aumento de risco de doenças vasculares (28). Nessa perspectiva, é possível destacar os resultados positivos do EF na função vascular (43, 44), redução da pressão arterial (9, 45) e redução de risco para doenças cardiovasculares (46). Quando realizados de maneira isolada, tanto o ER quanto o EA apresentam resultados positivos na função vascular. DeSouza et al. (43), avaliando os efeitos do EA na função vascular de homens de meia idade e idosos, demonstraram que o exercício aeróbio regular é capaz de prevenir e restaurar as perdas na função endotelial associadas ao envelhecimento e estilo de vida sedentário. Em outro estudo, desta vez envolvendo exercícios de força, incrementos no fluxo sanguíneo femoral basal e na complacência vascular de homens de meia idade e idosos submetidos a 13 semanas de TR foram encontrados (44). Quando associados, a ordem de realização desses dois modelos de exercício pode influenciar a resposta vascular, e a realização do ER anteriormente ao EA é a ordem de execução mais adequada para melhorar a função vascular (47). Em conjunto, tais achados demonstram a importância da prática de diferentes tipos de EF no combate aos efeitos deletérios do processo de envelhecimento e redução de riscos cardiovasculares.

2.5 *Hipertensão arterial e exercício físico*

A elevação sustentada da pressão arterial (PA) sistólica (> 140 mmHg) ou diastólica (> 90 mmHg) de consultório caracteriza a hipertensão arterial – HAS (48), condição clínica que acomete 68% (IC95%: 65.1-69.4%) dos indivíduos idosos brasileiros (49) e, em virtude da alta prevalência e das baixas taxas de controle (50, 51), é considerada um dos principais fatores de risco modificáveis e um dos mais importantes problemas de saúde pública (52). De acordo com os resultados de uma importante metanálise, aumentos de 10 mmHg e 5 mmHg nas PA sistólica e diastólica, respectivamente, estão associadas com aumento de 40% no risco de morte por acidente vascular cerebral e 30% por morte por outras DCVs (53).

Embora o tratamento da HAS seja feito através do uso de medicamentos, algumas mudanças no estilo de vida são capazes de auxiliar na prevenção e tratamento da HAS. Dentre essas mudanças, a prática regular de EF vem recebendo grande atenção por parte da comunidade científica e tem sido alvo de diversas investigações. Diversos estudos demonstraram efeitos benéficos do exercício físico na redução crônica da PA (35, 45, 48, 54-56), podendo essa diminuição ser resultado da somação dos efeitos hipotensores que ocorrem nas horas seguintes à sessão de exercício (57). Essa queda sustentada dos níveis pressóricos resultantes de uma única sessão de exercícios é denominada hipotensão pós-exercício (HPE) (58).

Dois principais mecanismos estão associados a redução de PA nas horas seguintes a realização de uma sessão de EF: o débito cardíaco (DC) e a resistência vascular periférica (RVP) (59-61). Considerando que a PA média é o produto funcional dessas duas variáveis (62), a diminuição de uma delas, sem o aumento proporcional da outra, resulta em menores valores de PA. Uma revisão recente apontou o DC como o mecanismo mais responsivo em indivíduos jovens e a RVP em indivíduos idosos (61). Entretanto, a partir da escassez de estudos avaliando esses mecanismos na população idosa, novas pesquisas são necessárias para um melhor entendimento dos mecanismos associados a HPE.

A magnitude e a duração da HPE está diretamente ligada a população estudada, apresentando melhores respostas em indivíduos hipertensos, quando comparado aqueles normotensos (63). Entretanto, ao compararmos homens e mulheres com características semelhantes, a PA parece responder de maneira similar após a realização de um mesmo protocolo de exercícios (64).

Assim como o tratamento com medicamentos anti-hipertensivos, o EF necessita ser prescrito na dose correta para ser efetivo na redução da PA. Embora diferentes volumes (65, 66) e intensidades (67, 68) tenham demonstrado eficácia na redução da PA, parece existir uma relação dose-resposta entre a magnitude do efeito e o volume ou intensidade do EF. Guidry et al. (65) demonstraram que diferentes volumes de EA (20 min e 40 min) foram efetivos na redução de PA sistólica, mas que apenas a sessão de maior volume apresentou diferença significativa em relação a sessão controle na PA média, quando o EA foi realizado em intensidade baixa (40% VO_{2max}). Em outro interessante estudo desse mesmo grupo de pesquisadores (67), o EA de maior intensidade (100% VO_{2max}) atingiu uma maior magnitude de redução na PA diastólica ao longo de 9h após a sessão, quando comparada as demais intensidades (40% e 60% VO_{2max}). No ER, séries múltiplas demonstraram maior HPE quando comparadas as séries simples em idosos hipertensos (66). Da mesma forma, maiores intensidades (50%1RM) promoveram resultados superiores, quando comparadas as sessões menos intensas (80%1RM) em indivíduos idosos hipertensos (68).

Nos estudos sobre HPE, tanto a resposta imediata (até 120 minutos após a sessão), como o efeito mais prolongado (até 24 horas após a sessão) dos diferentes modelos de EF vêm sendo investigados.

A resposta imediata de diferentes sessões de exercício tem demonstrado a efetividade do EF sobre a redução da PA (57, 60, 69). Entretanto, para que a redução seja clinicamente relevante, a hipotensão pós-exercício deve ter uma magnitude de alguns mmHg e a redução deve ser sustentada por um período relativamente prolongado (70). Nesse sentido, é possível encontrar alguns estudos avaliando os efeitos do EF sobre a PA de indivíduos hipertensos submetidos a diferentes protocolos de exercícios e monitorados ao longo de várias horas após a realização desses protocolos (Tabela 2).

Tabela 2: Ensaios clínicos randomizados cruzados de hipotensão pós-exercício em indivíduos hipertensos. Resultados apresentados através da diferença média de PA (MAPA, mmHg) dos dias de exercício versus dia controle.

Referência (ano)	Gênero/ Idade (média±DP)	Uso de Medicamentos durante as intervenções	PA casual, em mmHg (média±DP ou EP)	Intervenções: Volume/ Intensidade	Resultados principais (PA sistólica e diastólica, respectivamente)
Pescatello et al. (1991)	Homens 44±4 anos	Não	PAS: 136±2 PAD: 91±2	TA: 2 x 30 min/ 40-70% VO_{2max} C: Sem exercicio	PA diurna: 10 mmHg/ 4 mmHg PA noturna: - PA 24h: -
Wallace et al. (1999)	Homens e mulheres 48±12 anos	Não	PAS: 141±14 PAD: 97±10	TA: 50 min/ 50% VO_{2max} C: Sem exercicio	PA diurna: valor não informado (significativo) PA noturna: valor não informado (significativo) PA 24h: valor não informado (significativo)
Taylor-Tolbert et al. (2000)	Homens 60±2 anos	Não	PAS: 153±2 PAD: 96±2	TA: 3 x 15 min/ 70% VO_{2max} C: 45 min sem exercício	PA diurna: 9 mmHg/ 4 mmHg PA noturna: 6 mmHg/ 4 mmHg PA 24h: 7 mmHg/ 4 mmHg
Brandão Rondon et al. (2002)	Homens e mulheres 69±2 anos	Não	PAS: 157±4 PAD: 93±2	TA: 45 min/ 50% VO_{2max} C: 45 min sem exercício	PA diurna: valor não informado (significativo) PA noturna: valor não informado (significativo) PA 24h: valor não informado (significativo)
Guidry et al. (2006)	Homens 43±2 anos	Não	PAS: 126±1 PAD: 87±1	TA: 20 min/ 40-60% VO_{2max} TA: 40 min/ 40-60% VO_{2max} C: Sem exercício	PA diurna: 4-6 mmHg/ PAD s/ diferenças vs. C PA noturna: - PA 24h: -

Melo et al. (2006)	Mulheres	Sim	PAS: 134±5	TR: 6 exercícios/ 3 x 20 rep. 40%1RM	PA diurna: 7 mmHg/ 5 mmHg
	45±1 anos		PAD: 89±3	C: Sem exercício	PA noturna: s/ diferenças vs. C
					PA 24h: s/ diferenças vs. C
Eicher et al. (2010)	Homens	Não	PAS: 128±2	TA1: 40 min/ 40% VO_{2max}	PA diurna: 5-12 mmHg (TA2-TA3 vs.C / 5 mmHg (TA3 vs. C)
	44±1 anos		PAD: 88±1	TA2: 40 min/ 60% VO_{2max}	PA noturna: -
				TA3: Teste máximo/ 100% VO_{2max}	PA 24h: -
				C: 40 min sem exercício	
Terblanche & Millen (2012)	Homens e mulheres	Não	PAS: 145±13	TC - 30 min (60-80%VO_{2max}) + 25 min TR	PA diurna:8 mmHg/ PAD s/ diferenças vs. C
	52±10 anos		PAD: 94±12	TAQ - 30 min (60-80%VO_{2max}) + 25 min TR	PA noturna: 8-9 mmHg/ PAD s/ diferenças vs. C
				C - 55 min sem exercício	PA 24h: 9-8 mmHg/ PAD s/ diferenças vs. C
Queiroz et al. (2014)	Homens	Não	PAS: 134±3	TR: 40 min/ 7 exercícios - 3 x max. 50%1RM	PA diurna: s/ diferenças vs. C
	50±3 anos		PAD: 94±1	C: 40 min sem exercício	PA noturna: s/ diferenças vs. C
					PA 24h: s/ diferenças vs. C

PAS - pressão arterial sistólica; PAD - pressão arterial diastólica; TR - treinamento resistido; TA - treinamento aeróbio; TAQ - treinamento aquático; C - sessão controle; TC - treinamento concorrente em meio terrestre; 1RM: Uma repetição máxima; RM: repetições máximas; VO2max - consumo máximo de oxigênio; PA - pressão arterial; DP: desvio-padrão; EP: erro-padrão

Percebe-se, a partir dos resultados apresentados na Tabela 2, que diferentes tipos de exercício, bem como diferentes volumes e intensidades estão associados a diferentes magnitudes de respostas de PA. Da mesma forma, para aqueles indivíduos com valores iniciais mais elevados de PA, a pressão sistólica parece ser mais responsiva a uma sessão de exercícios, atingindo magnitudes de redução maiores do que a PA diastólica.

Até o presente momento, poucos estudos avaliaram os efeitos de uma sessão de treinamento concorrente na pressão arterial durante os minutos que sucedem essa sessão. Keese et al. (57) compararam a resposta imediata de PA após diferentes tipos de exercício (força, aeróbio e concorrente) em homens jovens normotensos. Todos os tipos de exercício demonstraram HPE, sendo esse efeito mais prolongado após as sessões de exercício aeróbio e concorrente (120 min) para PAS e após o exercício aeróbio para PAD (50 min). Outro estudo recente (71) avaliou a influência da ordem de execução dos treinamentos dentro da sessão de treinamento concorrente (i.e., Força→ Aeróbio ou Aeróbio → Força) na resposta imediata de PA de mulheres pós menopáusicas hipertensas e demonstrou que a ordem de execução não influenciou a resposta de PA ao longo de 30 minutos após cada sessão. Na presente revisão, nenhum artigo avaliando o efeito mais prolongado do exercício combinado de força e aeróbio na PA de idosos hipertensos foi encontrado.

Considerando a escassez de estudos avaliando os efeitos do treinamento concorrente e a importância clínica de se obter HPE, especialmente por períodos prolongados (70), novas investigações são necessárias na tentativa de se avaliar o impacto de uma sessão de treinamento concorrente na PA de indivíduos hipertensos.

3. JUSTIFICATIVAS

3.1 *Ensaio clínico randomizado 1*

De acordo com as lacunas anteriormente delimitadas, referentes a qual o número ideal de sessões semanais para otimizar incrementos nas principais variáveis neuromusculares e cardiorrespiratórias? Qual o número ideal de sessões semanais associado a menor risco para doenças do sistema cardiovascular? É possível obterem-se novos benefícios nessas variáveis em indivíduos com experiência prévia em TF e TA? O presente estudo justifica-se pela necessidade de desenvolver métodos eficientes de treinamento para serem utilizados como ferramentas para promoção da saúde e qualidade de vida de indivíduos idosos.

3.2 *Ensaio clínico randomizado 2*

É fundamental o desenvolvimento de modelos de exercício que sejam eficazes na redução da pressão arterial da população idosa. As lacunas anteriormente citadas, referentes à necessidade de se desenvolverem estratégias de exercício que promovam benefícios prolongados sobre a redução de pressão arterial em indivíduos hipertensos, constituem a base da justificativa para a busca de treinamentos que aumentem a adesão de idosos a programas de exercícios e ainda sejam eficientes para reduzir a pressão arterial.

4. OBJETIVOS

4.1 *Ensaio clínico randomizado 1*

4.1.1 Objetivo Geral

Avaliar os efeitos do número de sessões semanais de treinamento concorrente nas adaptações cardiovasculares e neuromusculares de homens idosos treinados.

4.1.2 Objetivos Específicos

Avaliar os efeitos de 2 e 3 sessões semanais de treinamento concorrente nas seguintes variáveis:

- Cardiovasculares - Consumo máximo de oxigênio, pressão arterial, fluxo sanguíneo e hiperemia reativa.
- Neuromusculares - Força máxima, potência muscular e espessura muscular.

4.2 *Ensaio clínico randomizado 2*

4.2.1 Objetivo Geral

Comparar a variação da pressão arterial pós-exercício em indivíduos idosos submetidos a exercício aeróbio, combinado ou sessão controle.

4.2.2 Objetivos Específicos

Comparar variação da pressão arterial medida nos 60 minutos após as sessões experimentais ou controle através de método oscilométrico.

Comparar a variação da pressão arterial aferida através de monitorização ambulatorial da pressão arterial (MAPA) para pressão sistólica de 24 h, diurna e noturna e pressão diastólica de 24 horas, diurna e noturna, durante e após as sessões experimentais ou controle.

5. REFERÊNCIAS

1. Chatterji S, Byles J, Cutler D, Seeman T, Verdes E. Health, functioning, and disability in older adults--present status and future implications. Lancet. 2015;385(9967):563-75.

2. Mathers CD, Stevens GA, Boerma T, White RA, Tobias MI. Causes of international increases in older age life expectancy. Lancet. 2015;385(9967):540-8.

3. Prince MJ, Wu F, Guo Y, Gutierrez Robledo LM, O'Donnell M, Sullivan R, et al. The burden of disease in older people and implications for health policy and practice. Lancet. 2015;385(9967):549-62.

4. Aagaard P, Magnusson PS, Larsson B, Kjaer M, Krustrup P. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. Medicine and science in sports and exercise. 2007;39(11):1989-96.

5. Fleg JL, Morrell CH, Bos AG, Brant LJ, Talbot LA, Wright JG, et al. Accelerated longitudinal decline of aerobic capacity in healthy older adults. Circulation. 2005;112(5):674-82.

6. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. Journal of applied physiology. 2003;95(5):1851-60.

7. American College of Sports M, Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Medicine and science in sports and exercise. 2009;41(7):1510-30.

8. Rikli RE, Jones CJ. Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. The Gerontologist. 2013;53(2):255-67.

9. Nualnim N, Parkhurst K, Dhindsa M, Tarumi T, Vavrek J, Tanaka H. Effects of swimming training on blood pressure and vascular function in adults >50 years of age. The American journal of cardiology. 2012;109(7):1005-10.

10. Ferrari R, Kruel LF, Cadore EL, Alberton CL, Izquierdo M, Conceicao M, et al. Efficiency of twice weekly concurrent training in trained elderly men. Experimental gerontology. 2013;48(11):1236-42.

11. Izquierdo M, Ibanez J, K HA, Kraemer WJ, Larrion JL, Gorostiaga EM. Once weekly combined resistance and cardiovascular training in healthy older men. Medicine and science in sports and exercise. 2004;36(3):435-43.

12. Izquierdo M, Hakkinen K, Anton A, Garrues M, Ibanez J, Ruesta M, et al. Maximal strength and power, endurance performance, and serum hormones in middle-aged and elderly men. Medicine and science in sports and exercise. 2001;33(9):1577-87.

13. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. Medicine and science in sports and exercise. 2010;42(5):902-14.

14. Pahor M, Guralnik JM, Ambrosius WT, Blair S, Bonds DE, Church TS, et al. Effect of structured physical activity on prevention of major mobility disability in older adults: the LIFE study randomized clinical trial. Jama. 2014;311(23):2387-96.

15. Sassen B, Cornelissen VA, Kiers H, Wittink H, Kok G, Vanhees L. Physical fitness matters more than physical activity in controlling cardiovascular disease risk factors. European journal of cardiovascular prevention and rehabilitation : official journal of the European Society of Cardiology, Working Groups on Epidemiology & Prevention and Cardiac Rehabilitation and Exercise Physiology. 2009;16(6):677-83.

16. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. Exercise and sport sciences reviews. 2012;40(1):4-12.

17. Pedersen BK, Saltin B. Exercise as medicine - evidence for prescribing exercise as therapy in 26 different chronic diseases. Scandinavian journal of medicine & science in sports. 2015;25 Suppl 3:1-72.

18. Kokkinos P, Doumas M, Myers J, Faselis C, Manolis A, Pittaras A, et al. A graded association of exercise capacity and all-cause mortality in males with high-normal blood pressure. Blood pressure. 2009;18(5):261-7.

19. Blair SN, Kampert JB, Kohl HW, 3rd, Barlow CE, Macera CA, Paffenbarger RS, Jr., et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. Jama. 1996;276(3):205-10.

20. Lee DC, Artero EG, Sui X, Blair SN. Mortality trends in the general population: the importance of cardiorespiratory fitness. Journal of psychopharmacology. 2010;24(4 Suppl):27-35.

21. Ruiz JR, Sui X, Lobelo F, Morrow JR, Jr., Jackson AW, Sjostrom M, et al. Association between muscular strength and mortality in men: prospective cohort study. Bmj. 2008;337:a439.

22. Cadore EL, Izquierdo M, Alberton CL, Pinto RS, Conceicao M, Cunha G, et al. Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. Experimental gerontology. 2012;47(2):164-9.
23. Picorelli AM, Pereira LS, Pereira DS, Felicio D, Sherrington C. Adherence to exercise programs for older people is influenced by program characteristics and personal factors: a systematic review. Journal of physiotherapy. 2014;60(3):151-6.
24. Reichert FF, Barros AJ, Domingues MR, Hallal PC. The role of perceived personal barriers to engagement in leisure-time physical activity. American journal of public health. 2007;97(3):515-9.
25. Hass CJ, Feigenbaum MS, Franklin BA. Prescription of resistance training for healthy populations. Sports medicine. 2001;31(14):953-64.
26. Kalapotharakos V, Smilios I, Parlavatzas A, Tokmakidis SP. The effect of moderate resistance strength training and detraining on muscle strength and power in older men. Journal of geriatric physical therapy. 2007;30(3):109-13.
27. Hepple RT, Mackinnon SL, Goodman JM, Thomas SG, Plyley MJ. Resistance and aerobic training in older men: effects on VO2peak and the capillary supply to skeletal muscle. Journal of applied physiology. 1997;82(4):1305-10.
28. Seals DR, Desouza CA, Donato AJ, Tanaka H. Habitual exercise and arterial aging. Journal of applied physiology. 2008;105(4):1323-32.
29. Wood RH, Reyes R, Welsch MA, Favaloro-Sabatier J, Sabatier M, Matthew Lee C, et al. Concurrent cardiovascular and resistance training in healthy older adults. Medicine and science in sports and exercise. 2001;33(10):1751-8.
30. Silva RF, Cadore EL, Kothe G, Guedes M, Alberton CL, Pinto SS, et al. Concurrent training with different aerobic exercises. International journal of sports medicine. 2012;33(8):627-34.
31. Hickson RC. Interference of strength development by simultaneously training for strength and endurance. European journal of applied physiology and occupational physiology. 1980;45(2-3):255-63.
32. Cadore EL, Pinto RS, Lhullier FL, Correa CS, Alberton CL, Pinto SS, et al. Physiological effects of concurrent training in elderly men. International journal of sports medicine. 2010;31(10):689-97.
33. Hakkinen K, Alen M, Kraemer WJ, Gorostiaga E, Izquierdo M, Rusko H, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. European journal of applied physiology. 2003;89(1):42-52.

34. Kraemer WJ, Patton JF, Gordon SE, Harman EA, Deschenes MR, Reynolds K, et al. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. Journal of applied physiology. 1995;78(3):976-89.

35. Sillanpaa E, Hakkinen A, Nyman K, Mattila M, Cheng S, Karavirta L, et al. Body composition and fitness during strength and/or endurance training in older men. Medicine and science in sports and exercise. 2008;40(5):950-8.

36. Wilhelm EN, Rech A, Minozzo F, Botton CE, Radaelli R, Teixeira BC, et al. Concurrent strength and endurance training exercise sequence does not affect neuromuscular adaptations in older men. Experimental gerontology. 2014;60:207-14.

37. Petrella JK, Kim JS, Tuggle SC, Bamman MM. Contributions of force and velocity to improved power with progressive resistance training in young and older adults. European journal of applied physiology. 2007;99(4):343-51.

38. Pinto SS, Alberton CL, Bagatini NC, Zaffari P, Cadore EL, Radaelli R, et al. Neuromuscular adaptations to water-based concurrent training in postmenopausal women: effects of intrasession exercise sequence. Age. 2015;37(1):9751.

39. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Medicine and science in sports and exercise. 2004;36(4):674-88.

40. Taaffe DR, Duret C, Wheeler S, Marcus R. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. Journal of the American Geriatrics Society. 1999;47(10):1208-14.

41. O'Donovan G, Owen A, Bird SR, Kearney EM, Nevill AM, Jones DW, et al. Changes in cardiorespiratory fitness and coronary heart disease risk factors following 24 wk of moderate- or high-intensity exercise of equal energy cost. Journal of applied physiology. 2005;98(5):1619-25.

42. Sayer AA, Robinson SM, Patel HP, Shavlakadze T, Cooper C, Grounds MD. New horizons in the pathogenesis, diagnosis and management of sarcopenia. Age and ageing. 2013;42(2):145-50.

43. DeSouza CA, Shapiro LF, Clevenger CM, Dinenno FA, Monahan KD, Tanaka H, et al. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. Circulation. 2000;102(12):1351-7.

44. Anton MM, Cortez-Cooper MY, DeVan AE, Neidre DB, Cook JN, Tanaka H. Resistance training increases basal limb blood flow and vascular conductance in aging humans. Journal of applied physiology. 2006;101(5):1351-5.

45. Moraes MR, Bacurau RF, Casarini DE, Jara ZP, Ronchi FA, Almeida SS, et al. Chronic conventional resistance exercise reduces blood pressure in stage 1 hypertensive men. Journal of strength and conditioning research / National Strength & Conditioning Association. 2012;26(4):1122-9.

46. Santos-Parker JR, LaRocca TJ, Seals DR. Aerobic exercise and other healthy lifestyle factors that influence vascular aging. Advances in physiology education. 2014;38(4):296-307.

47. Okamoto T, Masuhara M, Ikuta K. Combined aerobic and resistance training and vascular function: effect of aerobic exercise before and after resistance training. Journal of applied physiology. 2007;103(5):1655-61.

48. Cornelissen VA, Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. Journal of the American Heart Association. 2013;2(1):e004473.

49. Picon RV, Fuchs FD, Moreira LB, Fuchs SC. Prevalence of hypertension among elderly persons in urban Brazil: a systematic review with meta-analysis. American journal of hypertension. 2013;26(4):541-8.

50. Fuchs FD, Gus M, Moreira WD, Moreira LB, Moraes RS, Rosito GA, et al. Blood pressure effects of antihypertensive drugs and changes in lifestyle in a Brazilian hypertensive cohort. Journal of hypertension. 1997;15(7):783-92.

51. Gus I, Harzheim E, Zaslavsky C, Medina C, Gus M. Prevalence, awareness, and control of systemic arterial hypertension in the state of Rio Grande do Sul. Arquivos brasileiros de cardiologia. 2004;83(5):429-33; 4-8.

52. Sociedade Brasileira de C, Sociedade Brasileira de H, Sociedade Brasileira de N. [VI Brazilian Guidelines on Hypertension]. Arquivos brasileiros de cardiologia. 2010;95(1 Suppl):1-51.

53. Lewington S, Clarke R, Qizilbash N, Peto R, Collins R, Prospective Studies C. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet. 2002;360(9349):1903-13.

54. Sillanpaa E, Hakkinen A, Punnonen K, Hakkinen K, Laaksonen DE. Effects of strength and endurance training on metabolic risk factors in healthy 40-65-year-old men. Scandinavian journal of medicine & science in sports. 2009;19(6):885-95.

55. Cornelissen VA, Buys R, Smart NA. Endurance exercise beneficially affects ambulatory blood pressure: a systematic review and meta-analysis. Journal of hypertension. 2013;31(4):639-48.

56. Millar PJ, McGowan CL, Cornelissen VA, Araujo CG, Swaine IL. Evidence for the role of isometric exercise training in reducing blood pressure: potential mechanisms and future directions. Sports medicine. 2014;44(3):345-56.

57. Keese F, Farinatti P, Pescatello L, Monteiro W. A comparison of the immediate effects of resistance, aerobic, and concurrent exercise on postexercise hypotension. Journal of strength and conditioning research / National Strength & Conditioning Association. 2011;25(5):1429-36.

58. Kenney MJ, Seals DR. Postexercise hypotension. Key features, mechanisms, and clinical significance. Hypertension. 1993;22(5):653-64.

59. Hagberg JM, Montain SJ, Martin WH, 3rd. Blood pressure and hemodynamic responses after exercise in older hypertensives. Journal of applied physiology. 1987;63(1):270-6.

60. Rezk CC, Marrache RC, Tinucci T, Mion D, Jr., Forjaz CL. Post-resistance exercise hypotension, hemodynamics, and heart rate variability: influence of exercise intensity. European journal of applied physiology. 2006;98(1):105-12.

61. Brito LC, Queiroz AC, Forjaz CL. Influence of population and exercise protocol characteristics on hemodynamic determinants of post-aerobic exercise hypotension. Brazilian journal of medical and biological research = Revista brasileira de pesquisas medicas e biologicas / Sociedade Brasileira de Biofisica [et al]. 2014;47(8):626-36.

62. MacDonald JR. Potential causes, mechanisms, and implications of post exercise hypotension. Journal of human hypertension. 2002;16(4):225-36.

63. Queiroz AC, Sousa JC, Cavalli AA, Silva ND, Jr., Costa LA, Tobaldini E, et al. Post-resistance exercise hemodynamic and autonomic responses: Comparison between normotensive and hypertensive men. Scandinavian journal of medicine & science in sports. 2015;25(4):486-94.

64. Queiroz AC, Rezk CC, Teixeira L, Tinucci T, Mion D, Forjaz CL. Gender influence on post-resistance exercise hypotension and hemodynamics. International journal of sports medicine. 2013;34(11):939-44.

65. Guidry MA, Blanchard BE, Thompson PD, Maresh CM, Seip RL, Taylor AL, et al. The influence of short and long duration on the blood pressure response to an acute bout of dynamic exercise. American heart journal. 2006;151(6):1322 e5-12.

66. Brito Ade F, de Oliveira CV, Brasileiro-Santos Mdo S, Santos Ada C. Resistance exercise with different volumes: blood pressure response and forearm blood flow in the hypertensive elderly. Clinical interventions in aging. 2014;9:2151-8.

67. Eicher JD, Maresh CM, Tsongalis GJ, Thompson PD, Pescatello LS. The additive blood pressure lowering effects of exercise intensity on post-exercise hypotension. American heart journal. 2010;160(3):513-20.

68. Brito Ade F, de Oliveira CV, Santos Mdo S, Santos Ada C. High-intensity exercise promotes postexercise hypotension greater than moderate intensity in elderly hypertensive individuals. Clinical physiology and functional imaging. 2014;34(2):126-32.

69. Pescatello LS, Guidry MA, Blanchard BE, Kerr A, Taylor AL, Johnson AN, et al. Exercise intensity alters postexercise hypotension. Journal of hypertension. 2004;22(10):1881-8.

70. Cardoso CG, Jr., Gomides RS, Queiroz AC, Pinto LG, da Silveira Lobo F, Tinucci T, et al. Acute and chronic effects of aerobic and resistance exercise on ambulatory blood pressure. Clinics. 2010;65(3):317-25.

71. Meneses AL, Forjaz CL, de Lima PF, Batista RM, Monteiro Mde F, Ritti-Dias RM. Influence of endurance and resistance exercise order on the postexercise hemodynamic responses in hypertensive women. Journal of strength and conditioning research / National Strength & Conditioning Association. 2015;29(3):612-8.

6. ARTIGOS

6.1 *Ensaio clínico randomizado 1*

ARTIGO1: Efficiency of twice weekly concurrent training in trained elderly men

ARTIGO 2: Effects of different concurrent training frequencies on muscle power and muscle quality in trained elderly men: A randomized clinical trial

6.2 *Ensaio clínico randomizado 2*

ARTIGO 3: Effects of different exercises on post-exercise blood pressure in elderly hypertensive men: A crossover randomized clinical trial

Experimental Gerontology 48 (2013) 1236–1242

Contents lists available at ScienceDirect

Experimental Gerontology

journal homepage: www.elsevier.com/locate/expgero

Efficiency of twice weekly concurrent training in trained elderly men ☆

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A R T I C L E I N F O

Article history:
Received 2 July 2013
Received in revised form 23 July 2013
Accepted 30 July 2013
Available online 7 August 2013

Section Editor: Christiaan Leeuwenburgh

Keywords:
Exercise volume
Strength
Endurance
Dose–response
Aging

A B S T R A C T

This study compared the effects of different weekly training frequencies on the cardiovascular and neuromuscular adaptations induced by concurrent training in previously trained elderly. After 20 weeks of combined strength and endurance training, twenty-four healthy elderly men (65 ± 4 years) were randomly placed into two frequency training groups: strength and endurance training performed twice a week (SE2, n = 12); or, strength and endurance training performed three times per week (SE3, n = 12). The interventions lasted 10 weeks and each group performed identical exercise intensity and volume per session. Before and after the exercise training, one maximum repetition test (1RM), isometric peak torque (PT), maximal surface electromyographic activity (EMG), as well as muscle thickness (MT) were examined. Additionally, peak oxygen uptake (VO_{2peak}), maximum aerobic workload (W_{max}), first and second ventilatory thresholds (VT_1 and VT_2) were evaluated. There were significant increases in upper and lower-body 1RM, MT, VO_{2peak}, VT_1 and VT_2, with no differences between groups. There were no changes after training in maximal EMG and isometric peak torque. W_{max} was improved only in SE3. After 10 weeks of training, twice weekly combined strength and endurance training leads to similar neuromuscular and cardiovascular adaptations as three times per week, demonstrating the efficiency of lower frequency of concurrent training in previously trained elderly men.

1. Introduction

Biological aging is associated with declines of different physiological systems, including the neuromuscular system, through the loss of strength, power and muscle mass (Aagaard et al., 2007; Izquierdo et al., 2001), as well as the cardiovascular system, which presents important declines in peak oxygen consumption (VO_{2peak}) (Astrand et al., 1973). These reductions are directly related to loss of mobility in older individuals, reducing the independence and quality of life for this population (Lauretani et al., 2003). Regular physical activity is a cornerstone intervention to counteract many age-associated diseases and increase functional independence (ACSM, 2009). Among the main benefits of physical activity in the elderly, increased VO_{2peak} as a result of endurance training (Cadore et al., 2012; Karavirta et al., 2009), as well as strength training-induced adaptations in the neuromuscular system (Cadore et al., 2010, 2012; Karavirta et al., 2011), may confer greater independence for older individuals to perform daily activities such as climbing stairs, sit/stand and balance themselves (Steib et al., 2010).

A combination of strength and endurance interventions (i.e., concurrent training) seems to be the most effective strategy to improve both neuromuscular and cardiovascular functions in elderly (Cadore et al., 2012; Izquierdo et al., 2004; Wood et al., 2001). However, excessive volumes of both strength and endurance training may compromise the neuromuscular adaptations in older subjects (Cadore et al., 2010). In addition, it has been shown that different strength training frequencies (1, 2 or 3 sessions per week) induced similar muscle strength gains in untrained older adults (DiFrancisco-Donoghue et al., 2007; Taaffe et al., 1999). Recently, Holviala et al. (2012) have shown that strength training performed twice a week promoted greater increases in muscle strength when compared with a frequency of once a week, after 21 weeks of training in previously strength trained elderly. Therefore, the training status (i.e., trained or untrained) may be related to the strength training dose–response in the elderly. In regard to the concurrent training, only one study has compared different volumes of training in elderly. Izquierdo et al. (2004) observed no differences in strength gains between strength training alone (twice a week) and concurrent training (performing strength exercises on one

☆ Funding: The present study was partially funded by grants from CNPq-Brazil, CAPES-Brazil and Hospital de Clínicas de Porto Alegre (FIPE-HCPA).
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http://dx.doi.org/10.1016/j.exger.2013.07.016

day, and endurance exercise on the other day). In addition, these authors reported similar cardiovascular adaptations between endurance training alone (twice a week) and the concurrent training group. Notwithstanding, it remains poorly understood whether previously concurrent trained subjects would present differential magnitude of neuromuscular and cardiovascular adaptations to distinct weekly frequency in sessions of concurrent training.

Since the knowledge of weekly frequency of concurrent training in trained elderly could contribute to optimize the exercise prescriptions, the purpose of the present study was to compare the effects of different training frequencies (i.e., 3 vs. 2 sessions per week) during concurrent training on neuromuscular and cardiovascular adaptations in previously trained elderly men. We hypothesized that both training groups would obtain similar neuromuscular adaptations. Further, to analyze the differences in training prescriptions more comprehensively, we evaluated cardiorespiratory variables, hypothesizing that greater exercise volume (three times per week) would promote greater cardiovascular gains.

2. Methods

2.1. Subjects

Twenty-four healthy elderly men (mean 64 years, range 60–75 years), previously engaged in a regular and systematic exercise program for the last 5 months, volunteered for the study after completing an ethical consent form. Subjects were carefully informed about the design of the study with special information about possible risks and discomforts. Subsequently, subjects were randomly placed into two groups: strength and endurance training performed twice a week (SE2, n = 12); and, strength and endurance training performed three times per week (SE3, n = 12). The study was conducted according to the Declaration of Helsinki and the protocol was approved by the local Institutional Review Board. Exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases (except controlled stage 1 hypertension). Subjects were not taking any medication with influence on hormonal and neuromuscular metabolism and were advised to maintain their normal dietary intake throughout the study. Medical evaluations were performed using health questionnaire and maximal exercise test with 12-lead electrocardiography (ECG). The physical characteristics of subjects are shown in Table 1. Body mass and height were measured using an analog scale (resolution of 0.1 kg) and stadiometer (resolution of 1 mm), respectively (Asimed, Camarate, Portugal). Body composition was assessed using skinfold technique (LANGE, Cambridge, United Kingdom). A seven-site skinfold equation was used to estimate body density (Jackson and Pollock, 1978) and body fat was subsequently calculated using the Siri equation (Siri, 1993).

2.2. Experimental design

In order to compare the physiological effects of different concurrent training volumes in trained elderly men, we assessed a group of subjects who previously performed 12 weeks of periodized strength and endurance training program, which has been previously described (Cadore et al., 2012). After these 12 weeks of high intensity and volume of concurrent training, the elderly men performed additional 8 weeks of training at constant volume and intensity (25 min of endurance training at self-selected intensity + 2 sets of 10–12 repetitions of strength training using the load correspondent to 15 repetition maximum), aimed to maintain the neuromuscular and cardiovascular adaptations achieved in the first 12 weeks. Throughout both of these training periods the frequency was 3 times per week. After that, subjects performed the intervention of 10 weeks of periodized concurrent training with either twice or thrice sessions per week. Despite the different number of training sessions per week (i.e., 3 × 2 sessions per week), both groups performed the same intensity and volume per session of concurrent training. Thus, in the present study, we investigated the efficiency of 2 sessions of concurrent training when compared with 3 sessions in previously trained elderly men. Before and after the last 10 weeks of training, the subjects were evaluated using variables related to neuromuscular and cardiovascular adaptations. The stability and reliability of the performance variables are reported elsewhere (Cadore et al., 2012, 2013). Each specific test at pre- and post-intervention was overseen by the same investigator, who was blinded to the training group, and was conducted on the same equipment with identical subject/equipment positioning. Experimental evaluations were carried out at the same time of day throughout the study, and different tests were conducted on separate days to avoid fatigue.

Table 1
Subjects' characteristics pre- and post-training. Mean ± SD.

	SE2 (n = 11)		SE3 (n = 12)	
	Pre-training	Post-training	Pre-training	Post-training
Age, year	63.2 ± 2.2	63.4 ± 2.2	65.7 ± 5.7	65.9 ± 5.7
Height, m	1.75 ± 0.6	1.75 ± 0.6	1.69 ± 0.3	1.69 ± 0.3
Body mass, kg	81.4 ± 10.5	80.9 ± 10.2	76.1 ± 6.3	75.9 ± 7.6
% body fat	27.8 ± 2.5	25.8 ± 3.7	26.2 ± 2.9	25.2 ± 2.6

Strength–endurance twice a week group (SE2); strength–endurance three times a week group (SE3); no significant differences between training groups.

2.3. Maximal dynamic strength

Maximal dynamic strength was assessed using the 1RM on bilateral elbow flexors and bilateral knee extensors. The subjects warmed up for 5 min on a cycle ergometer, stretched all major muscle groups, and performed specific movements with 1 set of 15 repetitions with light load (30% of the first test load) in exercise tests. Maximal load was determined with no more than five attempts with a 4-min recovery between sets (Silva et al., 2012). Each contraction (concentric and eccentric) lasted 2 s, controlled by an electronic metronome (Quartz, CA, USA). The test–retest reliability coefficients (ICC) were 0.96 for both exercises.

2.4. Muscle thickness

After at least 72 h without any vigorous physical activity, subjects initially rested during 15 min before the procedures, which occurred in a temperature-controlled room and supine position. The muscle thickness (MT) was measured using B-mode ultrasound (Philips, VMI, Belo Horizonte, MG, Brazil). A 7.5-MHz probe with a water-soluble transmission gel was placed on the skin perpendicular to the tissue interface. The images were digitalized and after they were analyzed in software Image-J (National Institutes of Health, USA, version 1.37). The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified, and the distance from the adipose tissue–muscle interface was defined as MT. The MT images were determined in the lower-body muscles vastus lateralis (VL), vastus medialis (VM), vastus intermedius (VI) and rectus femoris (RF). The measurement for the VL was taken at midway between the lateral condyle of the femur and greater trochanter (Kumagai et al., 2000), whereas the measurement for the VM was taken at 30% of the distance between the lateral condyle of the femur and the greater trochanter (Korhonen et al., 2009), yet the measurements for the VI and RF were measured as 60% the distance from the greater trochanter to the lateral epicondyle and 3 cm lateral to the midline of the anterior thigh (Chilibeck et al., 2004). In upper-body limbs, MT were obtained in the bíceps brachii (BB) and brachialis (BR) muscle mass. The site to elbow flexor measurement was at 40% of the distance from the lateral epicondyle to acromion process in scapula (Miyatani et al., 2002). To ensure identical placement in subsequent tests, the right thigh and arm of each subject were mapped for the position of anatomical points and small angiomas by marking on transparent paper (Cadore et al., 2012). The MT test–retest reliability coefficients (ICC) were 0.92 for BB, 0.93 for BR, 0.94 for VL, 0.91 for VM, 0.92 for VI and 0.95 for RF.

2.5. Isometric and isokinetic peak torque

The isometric knee extension test was measured using a Cybex Norm II Isokinetic Dynamometer (Lumex Co., Ronkonkoma, NY, USA), calibrated according to manufacturing standards prior to each day of testing. The warm up consisted of 15 submaximal isokinetic knee extension and flexion repetitions at $120° \cdot s^{-1}$. The subjects were maintained in position after adjustment of the height of the dynamometer and the length of the support, allowing the knee joint of the subjects to be aligned with the axis of rotation of the dynamometer. Each subject was stabilized at the chest, waist, and thigh with a strap. A shin strap was secured to the lower leg proximal to the malleoli; and the test was performed on the dominant limb (Silva et al., 2012). Isometric peak torque was determined during a 5-s maximal isometric knee extension at a knee angle of 60° full extension (= 0°). Three maximal 5-s isometric contractions were performed with 3-min rest intervals between each contraction. The contraction with the highest torque value was used in data analysis. The test–retest reliability coefficient (ICC) was 0.94 in the dynamometer test.

2.6. EMG measurements

During the isometric peak torque test, the maximal neuromuscular activity of agonist muscles was evaluated using surface electromyography (root mean square values — RMS) in the vastus lateralis and rectus femoris. Electrodes were positioned on the muscular belly in a bipolar configuration (20 mm interelectrode distance) in parallel with the orientation of the muscle fibers, as previously described (Cadore et al., 2013). Shaving and abrasion with alcohol were carried out on the muscular belly, in order to maintain the interelectrode resistance below 2000 Ω. To ensure the same electrode position in subsequent tests, the right thigh of each subject was mapped for the position of the electrode moles and small angiomas by marking on transparent paper (Cadore et al., 2012). The reference electrode was fixed on the anterior crest of the tibia. The raw EMG signal was acquired simultaneously with the MVC using a 4-channel electromyography (Miotool, Porto Alegre, Brazil), with a sampling frequency of 2000 Hz per channel, connected to a computer. Following the signal acquisition, data were exported to SAD32 software, and filtered by Butterworth band-pass filter, with a cutoff frequency of between 20 and 500 Hz. Thereafter, EMG records were sliced in 1 s during the MIVC plateau was determined in the force–time curve and RMS values were calculated. The test–retest reliability coefficient (ICC) of the EMG measurements was 0.85.

2.7. Peak oxygen consumption, maximum aerobic workload and ventilatory thresholds

Incremental testing on a cycle ergometer (Cybex, Ronkonkoma, NY, USA) was conducted in order to determine the VO_{2peak}, maximal workload (W_{max}), first (VT_1) and second (VT_2) ventilatory thresholds, and heart rate at VT_2 (HR_{VT2}). During the tests, subjects initially cycled with a 25 W load, which was progressively increased by 25 W every 2 min, while maintaining a cadence of 70–75 rpm, until exhaustion (Izquierdo et al., 2004). The test was halted when subjects were no longer able to maintain a cadence of over 70 rpm. All the incremental tests were supervised by a physician. The breath-by-breath expired gases were analyzed by a metabolic cart (CPX/D, Medical Graphics Corporation, St. Paul, MN, USA). VT_1 and VT_2 were determined through the ventilation curve and confirmed by curves of ventilatory equivalents for O_2 (VE/VO_2) and CO_2 (VE/VCO_2), respectively (Wasserman et al., 1973). Three experienced physiologists determined the corresponding points by visual inspection in a blinded procedure. The maximum VO_2 value ($ml \cdot kg^{-1} \cdot min^{-1}$) obtained close to exhaustion was considered as VO_{2peak}. The maximum test was considered valid if at least 2 of the 3 listed criteria were met: 1) maximum heart rate predicted by age was reached (220 − age); 2) impossibility of continuing to pedal at a minimum velocity of 70 rpm; and 3) respiratory exchange rate greater than 1.1 was obtained (Howley et al., 1995; Izquierdo et al., 2004). For the data analysis, curves of exhaled and inhaled gases were smoothed by visual analysis using the Cardiorespiratory Diagnostic Software Breeze Ex version 3.06. Heart rate (HR) was measured using a Polar monitor (model FS1, Shanghai, CHI). The test–retest reliability coefficients (ICC) were 0.88 to VO_{2peak} and W_{max}, as well as 0.85 to VT_1 and VT_2.

2.8. Concurrent training program

Both groups took part in a concurrent training program that lasted 10 weeks. They performed both strength and endurance training on the same session, in which the strength exercises were performed first and were immediately followed by the endurance exercise. Training groups performed the same exercise intensity and volume per session, and were different in the number of training sessions per week. The SE2 group trained on Mondays and Fridays, and the subjects of SE3 group trained on Mondays, Wednesdays and Fridays. All the training sessions were carefully supervised by at least 2 experienced personal trainers. The strength training program included nine exercises (inclined leg press, knee extension, leg curl, seated row, biceps curl, bench press, inverted fly, triceps curl and abdominal exercises) performed until failure (repetition maximum — RM). These exercises were chosen to emphasize both major and minor muscle groups, using single as well multi-joint exercises, based in the recommendation of ACSM (2009). During the first three weeks, subjects performed three sets of 12-10 RM, progressing to 10-8 RM (weeks 4–6) and finalizing with three sets of 8-6 RM (weeks 7-10). In each set the workload was adjusted when repetitions performed were either under or above the repetitions established (Cadore et al., 2010). The recovery between sets lasted 120 s. The endurance training program was performed on a cycle ergometer. Each session lasted 30 min and had the intensity individually monitored according to the HR_{VT2}, using a range between 85 and 95% of the HR_{VT2}. The whole concurrent training periodization is shown in Table 2.

2.9. Statistical analysis

Results are reported as mean ± SD. Normal distribution and homogeneity parameters were checked with Shapiro–Wilk and Levene tests respectively. The training-related effects were assessed using a two-way Analysis of Variance (ANOVA) with repeated measures (group × time). When the interaction was significant, the main factors group and time were tested again using t tests. Significance was accepted when $\alpha = 0.05$ and the SPSS statistical software package (version 17.0) were used to analyze all data. On the basis of a previous study with concurrent training performed in our laboratory (Cadore et al., 2012), we estimated that a sample size of 11 individuals would be required to identify a difference of approximately 25% levels of muscle strength with a statistical power of 85%, for an α of 0.05.

Table 2
Strength and endurance training periodization.

	Strength training		Endurance training	
	Sets per exercise	Rep. per set	Volume	Intensity
Weeks 1–3	3	12-10 RM	30 min	85% HR_{VT2}
Weeks 4–6	3	10-8 RM	30 min	90% HR_{VT2}
Weeks 7–10	3	8-6 RM	30 min	95% HR_{VT2}

RM: maximum repetitions; HRVT2: heart rate at second ventilatory threshold; Rep.: repetitions.

3. Results

One participant dropped out during the training period due to personal issues. At the end of the study, the number of subjects in each group was: SE2 = 11; and, SE3 = 12. All subjects performed at least 90% of training with no difference between groups in training compliance (mean SE2: 19.7 of 20 sessions and mean SE3: 29.1 of 30 sessions). The overall experimental design is demonstrated in Fig. 1, which illustrates the concurrent training effects on 1RM, muscle thickness, and VO_2peak (Fig. 1).

3.1. Maximal dynamic strength

At baseline, there were no differences between groups in upper (elbow flexors) and lower-body (knee extensors) 1 RM values. After training, there were increases ($p < 0.001$) in upper-body 1RM (SE2: 10.5 ± 4.6%; and, SE3: 7.1 ± 4.8%) and lower-body 1RM (SE2: 22.5 ± 9.5%; and, SE3: 19.7 ± 8.9%). No significant differences between groups were observed in the training-induced changes in upper and lower-body 1RM values (Fig. 2).

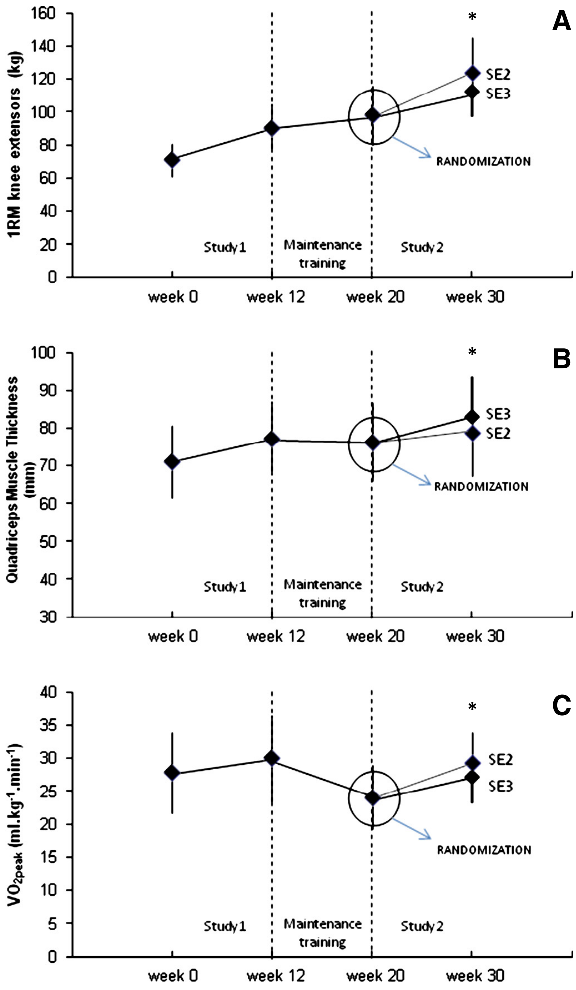

Fig. 1. Long-term effects of concurrent training on knee extensors maximal dynamic strength (1RM) (A), quadriceps muscle thickness (B), and peak oxygen consumption (VO_{2peak}) (C), strength–endurance twice a week group (SE2) and strength–endurance three times a week group (SE3). Study 1 refers to the first 12 weeks of concurrent training (Cadore et al., 2012). Values are means ± SD. *Significant difference from week 20 ($p < 0.001$).

3.2. Muscle thickness

At baseline, there were no differences between groups in lower-body (VL, RF, VM and VI) and upper-body muscle thickness (BB and BR). After training, there were increases ($p < 0.001$) in VL (SE2: 5.0 ± 3.5%; and, SE3: 6.3 ± 3.2%), RF (SE2: 4.6 ± 2.4%; and, SE3: 7.8 ± 5.5%), VI (SE2: 8.8 ± 5.9%; and, SE3: 12.9 ± 9.0%), and VM muscle thickness (SE2: 3.5 ± 2.7%; and, SE3: 4.1 ± 2.8%). In the upper-body muscle thickness, there were increases ($p < 0.001$) in BB (SE2: 4.6 ± 3.6%; and, SE3: 2.7 ± 1.0%) and BR (SE2: 10.2 ± 9.3%; and, SE3: 10.9 ± 5.6%). No significant differences between groups were observed in the training-induced changes in the lower and upper-body muscle thickness variables (Fig. 3 and Table 3).

3.3. Isometric peak torque

At baseline, groups did not differ in isometric peak torque values. No significant differences between groups were observed in the training-induced changes in isometric peak torque (Table 3).

3.4. EMG measurements

At baseline, there were no differences between groups in the maximal neuromuscular activity (maximal EMG amplitude) of VL and RF (Table 3). After training, there were no changes in the maximal neuromuscular activity of VL and RF.

3.5. Peak oxygen consumption, maximum aerobic workload and ventilatory thresholds

At baseline, there were no differences between groups in VO_{2peak}, W_{max}, VT_1 and VT_2. After training, both groups presented similar

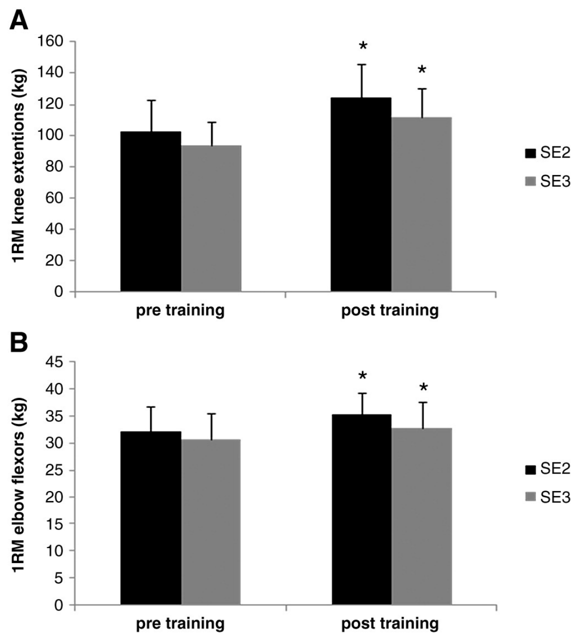

Fig. 2. Maximal dynamic strength (1RM) of knee extensors (A) and elbow flexors (B) pre- (week 20) and post-training. Strength–endurance twice a week group (SE2) and strength–endurance three times a week group (SE3). Values are means ± SD. *Significant difference from pre-training (week 20) values ($p < 0.001$).

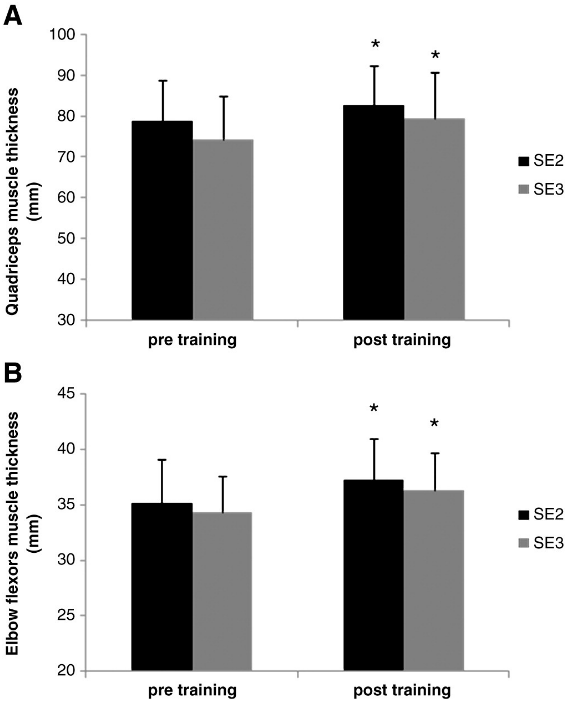

Fig. 3. Quadriceps muscle thickness (i.e., sum of the vastus lateralis, vastus medialis, vastus intermedius and rectus femoris muscle thicknesses) (A) and elbow flexor muscle thickness (i.e., sum of the bíceps brachii and brachialis muscle thicknesses) (B) pre- and post-training. Strength–endurance twice a week group (SE2) and strength–endurance three times a week group (SE3). Values are means ± SD. *Significant difference from pre-training values ($p < 0.001$).

increases in VO_{2peak} (SE2: 22.1 ± 10.7%; and, SE3: 14.2 ± 10.8%, $p < 0.001$). In W_{max}, there was significant time vs. group interaction ($p < 0.01$), in which changes were observed only in SE3 (13.3 ± 9.6%, $p < 0.01$). Both VT_1 (SE2: 18.3 ± 11.9%; and, SE3: 6.4 ± 18.2%) and VT_2 (SE2: 13.9 ± 16.7%; and, SE3: 4.6 ± 14.4%) increased after training ($p < 0.05$), with no differences between groups (Table 4).

4. Discussion

To our knowledge, this was the first study designed to compare in previously trained elderly groups the cardiovascular and neuromuscular effects of low-frequency ($2 \cdot wk^{-1}$) combined strength and endurance training with those attained in a high-frequency training approach

Table 4
Cardiovascular parameters pre- and post-training. Mean ± SD.

	SE2		SE3	
	Pre-training	Post-training	Pre-training	Post-training
VO_{2peak}, ml · kg · min^{-1}	22.3 ± 4.7	27.2 ± 4.5*	25.8 ± 4.9	29.4 ± 5.4*
W_{max}, watts	166.7 ± 37.5	169.4 ± 41	150 ± 35.4	167 ± 29*
VT_1, ml · kg · min^{-1}	12.9 ± 2.2	15 ± 2.4*	15.5 ± 3.4	16.2 ± 2.9*
VT_2, ml · kg · min^{-1}	17.8 ± 3.6	20 ± 2.7*	20.9 ± 4.2	21.7 ± 4.7*

Strength–endurance twice a week group (SE2); strength–endurance three times a week group (SE3); VO_2peak, peak oxygen uptake; Wmáx, maximal workload; VT_1 and VT_2, first and second ventilatory thresholds, respectively; Significant difference from pre-training values: *($p < 0.001$).

($3 \cdot wk^{-1}$). The main findings of the present study were the similar improvements in maximal muscle strength, MT and VO_{2peak} induced by concurrent training performed either 2 or 3 sessions per week in trained elderly men, whereas the maximal power on a cycle ergometer was improved only with 3 sessions per week. The present observations suggest the efficiency of concurrent training performed twice a week to enhance the overall physical fitness in previously trained elderly men. These findings may have important practical relevance for optimal construction of cardiovascular and neuromuscular training programs for older men since muscle strength, muscle power and endurance performance are important health-related fitness components in this population.

The reduction in muscle strength and endurance is a hallmark of the aging process (Aagaard et al., 2007; Astrand et al., 1973). In this regard, different types of exercise training benefit the older population by inducing increases in VO_{2peak}, muscle strength and functional capacity (Cadore and Izquierdo, 2013). However, such pieces of evidence have been primarily shown in previously untrained subjects (Cadore et al., 2010; Izquierdo et al., 2004; Karavirta et al., 2009, 2011; Sillanpää et al, 2008, 2009; Wood et al., 2001). A unique characteristic of the present study was the comparison in elderly men of different weekly frequencies in a previously 20 week trained group. Therefore, we chose to test the assessment of the frequency of exercise sessions due to its common manipulation in exercise programs. Both SE2 and SE3 groups kept improving their maximal values of strength, muscle mass, and VO_{2peak} at magnitudes comparable to those observed in the early-phase of training (Cadore et al., 2012) as well as to other studies investigating concurrent training adaptations in untrained elderly (Cadore et al., 2010; Izquierdo et al., 2004; Karavirta et al., 2009, 2011; Sillanpää et al, 2008; Wood et al., 2001).

Few studies investigated the effects of different training frequencies in elderly populations (DiFrancisco-Donoghue et al., 2007; Holviala et al., 2012; Taaffe et al., 1999). Taaffe et al. (1999) observed similar 1RM strength improvements induced by different frequencies of training (1 vs. 2 vs. 3 sessions per week) in untrained older adults. Holviala et al. (2012) showed that a twice-a-week training promoted greater strength

Table 3
Muscle thickness and maximal neuromuscular activity pre- and post-training. Mean ± SD.

	SE2		SE3	
	Pre-training	Post-training	Pre-training	Post-training
VL muscle thickness (mm)	22 ± 2.7	23.1 ± 2.8*	20.3 ± 2.8	21.5 ± 2.9*
VM muscle thickness (mm)	23 ± 4.3	23.8 ± 4.3*	23.3 ± 3.4	24.3 ± 3.8*
VI muscle thickness (mm)	15.9 ± 4.2	17.2 ± 4.4*	13.9 ± 3.4	15.5 ± 3.3*
RF muscle thickness (mm)	18.1 ± 2.9	18.9 ± 2.8*	17 ± 4.2	18.3 ± 4.4*
BB muscle thickness (mm)	23.2 ± 3.0	24.2 ± 2.8*	21.3 ± 2.6	21.9 ± 2.6*
BR muscle thickness (mm)	12 ± 2.3	13.2 ± 2.7*	13.1 ± 1.4	14.5 ± 1.4*
Isometric peak torque (Nm)	256.3 ± 52.1	255.4 ± 47.7	260.5 ± 43	243.3 ± 32.9
Maximal NA VL (μV)	392.7 ± 129.4	383.8 ± 167.3	438.2 ± 222.2	437.5 ± 132.6
Maximal NA RF (μV)	218.6 ± 97.3	204.9 ± 87.3	298.7 ± 112.4	280.2 ± 94.6

Strength–endurance twice a week group (SE2); strength–endurance three times a week group (SE3); VL, vastus lateralis; VM, vastus medialis; VI, vastus intermedius; RF, rectus femoris; BF, biceps femoris; BB, biceps brachii; BR, brachialis. Neuromuscular activity (NA) determined by maximal electromiographic signal amplitude. Pre- and post-training indicate values from the 10-week intervention. Significant difference from pre-training values: *($p < 0.001$).

gains than once-a-week, suggesting that a minimum volume may be necessary to improve maximal strength in trained subjects. In the present study, both SE2 and SE3 weekly frequencies promoted similar neuromuscular changes, indicating the efficiency of concurrent training performed twice a week in trained elderly men. It is possible that training 12 sets per week (SE2) achieved a threshold stimulus for muscle strength and muscle mass gains. More interestingly, our results indicated that adding 6 sets (SE3) in the weekly exercise program increased the maximal aerobic power, but did not further induce further improvements neither in muscle variables nor in VO_{2peak} of trained older subjects. In addition, it may be speculated that any possible advantages obtained with the greater weekly volume performed by SE3 group was compensated by lower recovery time between sessions (~48 h) and potentially limited muscle recovery in this group when compared with SE2 group (~72 h).

The absence of changes in maximal EMG amplitude of VL and RF muscles observed in both groups may be explained by the fact that EMG changes reflects neural adaptations, usually observed in early phases of training (Moritani and DeVries, 1979). In fact, the subjects of the present study had their maximal EMG amplitude improved in their first 12 weeks of training (Cadore et al., 2013). In addition, the EMG data were assessed during the isometric peak torque test, which presented no changes in our study.

It has been suggested that a minimum of 3 sessions per week of endurance training is necessary to increase VO_{2peak} in healthy middle-aged and older adults (ACSM, 2009). In older adults, positive effects of concurrent training on VO_{2peak} have been shown in previous studies with both twice (Izquierdo et al., 2004; Sillanpää et al., 2008) and thrice a week programs (Cadore et al., 2010, 2012). In the present study, both SE2 and SE3 groups showed similar increases in VO_{2peak}, VT_1 and VT_2, but only SE3 enhanced the W_{max}. These results suggest that higher concurrent training volumes might be necessary to elicit increases in maximal aerobic power. However, the similar increases observed in the VO_{2peak}, VT_1 and VT_2 in both weekly frequencies highlight the efficiency of a concurrent training program performed twice a week to promote cardiovascular benefits in elderly subjects. Such results have important clinical applications since the increase of VO_{2peak} is related with reduced risk of mortality (Lee et al., 2011), and exercise interventions which are effective in improving this parameter, with lower expenditure of time, may facilitate the training adherence.

Our findings also have implications for professionals designing exercise programs to improve health and fitness in the elderly population. In this regard, a twice weekly combined strength and endurance training would be more practical and efficient for older adults to optimize neuromuscular and cardiovascular training adaptations. The present data expand the knowledge of previous findings related to the efficiency of different weekly frequencies of training in an elderly population, since it shows that concurrent training performed twice a week is a sufficient stimulus to elicit maximal strength, muscle mass and VO_{2peak} gains.

In conclusion, in trained older men, concurrent training performed twice a week promotes similar increases in maximal dynamic strength and muscle thickness when compared to the same program performed three times per week. In addition, both weekly frequencies result in similar increases in cardiovascular variables. However, it should be mentioned that only three training sessions per week induced increases in maximal power on cycle ergometer in the previously trained elderly men. Finally, the low frequency of combined strength and endurance training for older adults may facilitate the adherence to exercise while also optimizing physical fitness at comparable benefits obtained in higher weekly frequencies.

Conflict of interest

The authors declare no duality of interest for the present manuscript.

Acknowledgments

This study was partially supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, PNPD 2818/2011).

References

Aagaard, P., Magnusson, O.S., Larsson, B., Kjker, M., Krustrup, P., 2007. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. Med. Sci. Sports Exerc. 39 (11), 1989–1996.
American College of Sports Medicine, 2009. Position stand: exercise and physical activity for older adults. Med. Sci. Sports Exerc. 41 (3), 1510–1530.
Astrand, I., Astrand, P.O., Hallback, I., Kilbom, A., 1973. Reduction in maximal oxygen uptake with age. J. Appl. Physiol. 35, 649–654.
Cadore, E.L., Izquierdo, M., 2013. How to simultaneously optimize muscle strength, power, functional capacity, and cardiovascular gains in elderly: an update. AGE. http://dx.doi.org/10.1007/s11357-012-9503-x (Dec 18 [Epub ahead of print]).
Cadore, E.L., Pinto, R.S., Lhullier, F.L.R., Correa, C.S., Alberton, C.L., Pinto, S.S., Almeida, A.P.V., Tartaruga, M.P., Silva, E.M., Kruel, L.F.M., 2010. Physiological effects of concurrent training in elderly men. Int. J. Sports Med. 31, 689–697.
Cadore, E.L., Izquierdo, M., Alberton, C.L., Pinto, R.S., Conceição, M., Cunha, G., Radaelli, R., Bottaro, M., Trindade, G.T., Kruel, L.F., 2012. Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. Exp. Gerontol. 47, 164–169.
Cadore, E.L., Izquierdo, M., Pinto, S.S., Alberton, C.L., Pinto, R.S., Baroni, B.M., Vaz, M.A., Lanferdini, F.J., Radaelli, R., González-Izal, M., Bottaro, M., Kruel, L.F., 2013. Neuromuscular adaptations to concurrent training in the elderly: effects of intrasession exercise sequence. AGE 35 (3), 891–903.
Chilibeck, P.D., Stride, D., Farthing, J.P., Burke, D.G., 2004. Effect of creatine ingestion after exercise on muscle thickness in males and females. Med. Sci. Sports Exerc. 36 (10), 1781–1788.
DiFrancisco-Donoghue, J., Weiner, W., Douris, P.C., 2007. Comparison of once-weekly and twice-weekly strength training in older adults. Br. J. Sports Med. 41 (1), 19–22.
Holviala, J., Häkkinen, A., Alen, M., Sallinen, J., Kraemer, W., Häkkinen, K., 2012. Effects of prolonged and maintenance strength training on force production, walking, and balance in aging women and men. Scand. J. Med. Sci. Sports. http://dx.doi.org/10.1111/j.1600-0838.2012.01470.x (Apr 29 [Epub ahead of print]).
Howley, E.T., Basset Jr., D.R., Welch, H.G., 1995. Criteria for maximal oxygen uptake: review and commentary. Med. Sci. Sports Exerc. 27, 1292–1301.
Izquierdo, M., Hakkinen, K., Ibanez, J., Antón, A., Garrués, M., Ruesta, M., Gorostiaga, E.M., 2001. Maximal strength and power, endurance performance, and serum hormones in middle-aged and elderly men. Med. Sci. Sports Exerc. 33 (9), 1577–1587.
Izquierdo, M., Ibañez, J., Häkkinen, K., Kraemer, W.J., Larrión, J.L., Gorostiaga, E.M., 2004. Once weekly combined resistance and cardiovascular training in healthy older men. Med. Sci. Sports Exerc. 36, 435–443.
Jackson, A.S., Pollock, M.L., 1978. Generalized equations for predicting body density of men. Br. J. Nutr. 40, 497–504.
Karavirta, L., Tulppo, M.P., Laaksonen, D.E., Nyman, K., Laukkanen, R.T., Kinnunen, H., Häkkinen, A., Häkkinen, K., 2009. Heart rate dynamics after combined endurance and strength training in older men. Med. Sci. Sports Exerc. 41, 1436–1443.
Karavirta, L., Häkkinen, A., Sillanpää, E., Garcia-Lopez, D., Kauhanen, A., Haapasaari, A., Alen, M., Pakarinen, A., Kraemer, W.J., Izquierdo, M., Gorostiaga, E.M., Häkkinen, K., 2011. Effects of combined endurance and strength training on muscle strength, power and hypertrophy in 40–67-year-old men. Scand. J. Med. Sci. Sports 21, 402–411.
Korhonen, M.T., Mero, A.A., Alen, M., Sipila, S., Hakkinen, K., Liikavainio, T., Viitasalo, J.T., Haverinen, M.T., Suominen, H., 2009. Biomechanical and skeletal muscle determinants of maximum running speed with aging. Med. Sci. Sports Exerc. 41, 844–856.
Kumagai, K., Abe, T., Brechue, W.F., Ryushi, T., Takano, S., Mizuno, M., 2000. Sprint performance is related with muscle fascicle length in male 100 m-sprinters. J. Appl. Physiol. 88, 811–816.
Lauretani, F., Russo, C.R., Bandinelli, S., Bartali, B., Cavazzini, C., Di Iorio, A., Corsi, A.M., Ferrucci, L., 2003. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. J. Appl. Physiol. 95, 1851–1860.
Lee, D.C., Sui, X., Artero, E.G., Lee, I.M., Church, T.S., McAuley, P.A., Stanford, F.C., Kohl, H.W., Blair, S.N., 2011. Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men: the Aerobics Center Longitudinal Study. Circulation 124 (23), 2483–2490.
Miyatani, M., Kanehisa, H., Kuno, S., Nishijima, T., Fukunaga, T., 2002. Validity of ultrasonograph muscle thickness measurements for estimating muscle volume of knee extensors in humans. Eur. J. Appl. Physiol. 86, 203–208.
Moritani, T., DeVries, H., 1979. Neural factors vs hypertrophy in the time course of muscle strength gain. Am. J. Phys. Med. 58, 115–130.
Sillanpää, E., Hakkinen, A., Nyman, K., Mattila, M., Cheng, S., Karavirta, L., Laaksonen, D., Huuhka, N., Kraemer, W.J., Hakkinen, K., 2008. Body composition and fitness during strength and/or endurance training in older men. Med. Sci. Sports Exerc. 40 (5), 950–958.
Sillanpää, E., Häkkinen, A., Punnonen, K., Häkkinen, K., Laaksonen, D.E., 2009. Effects of strength and endurance training on metabolic risk factors in healthy 40–65-year-old men. Scand. J. Med. Sci. Sports 19, 885–895.

Silva, R.F., Cadore, E.L., Kothe, G., Guedes, M., Alberton, C.L., Pinto, S.S., Pinto, R.S., Trindade, G., Kruel, L.F., 2012. Concurrent training with different aerobic exercises. Int. J. Sports Med. 33, 627–634.

Siri, W.E., 1993. Body composition from fluid spaces and density: analysis of methods. Nutrition 9, 480–491.

Steib, S., Schoene, D., Pfeifer, K., 2010. Dose–response relationship of resistance training in older adults: a meta-analysis. Med. Sci. Sports Exerc. 42 (5), 902–914.

Taaffe, D.R., Duret, C., Wheeler, S., Marcus, R., 1999. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. J. Am. Geriatr. Soc. 47 (10), 1208–1214.

Wasserman, K., Whipp, B.J., Koyal, S.N., Beaver, W.L., 1973. Anaerobic threshold and respiratory gas exchange during exercise. J. Appl. Physiol. 35, 236–243.

Wood, R.H., Reyes, R., Welsch, M.A., Favarolo-Sabatier, J., Sabatier, M., Lee, C.M., Johnson, L.G., Hooper, P.F., 2001. Concurrent cardiovascular and resistance training in healthy older adults. Med. Sci. Sports Exerc. 33, 1751–1758.

Effects of different concurrent training frequencies on muscle power and muscle quality in trained elderly men: A randomized clinical trial

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Word count: 2542

Abstract word count: 212

Number of tables and figures: 3

Abstract

Objectives: To compare the effects of different weekly training frequencies on muscle power and muscle quality induced by concurrent training in previously-trained elderly. **Design:** Randomized clinical trial **Methods:** Twenty-four previously-trained elderly men (65±4 years) were randomly allocated to concurrent strength and endurance training programs: twice a week (2/week, n=12) or three times per week (3/week, n=12). Each group performed identical exercise intensity and volume per session for 10 weeks. Before and after the exercise training, muscle power, estimated by countermovement jump height, knee extensor isokinetic peak torque at 60 and $180^{o}\cdot s^{-1}$, and Muscle quality, a quotient between one-repetition maximum of the knee extensors and the sum of quadriceps femoris muscle thickness determined by ultrasonography, were examined. Additionally, as secondary outcomes, blood pressure and reactive hyperemia were evaluated. **Results:** Muscular power (2/week: 7%, and 3/week: 10%) and muscle quality (2/week: 15%, and 3/week: 8%) improved with the concurrent exercise training ($p<0.01$), with no differences between groups. Isokinetic peak torque at 60 and $180^{o}\cdot s^{-1}$ increased in both groups ($p<0.05$). There were no changes in blood pressure or reactive hyperemia with the concurrent training. **Conclusion:** Concurrent training performed twice a week promotes similar adaptations in muscular power and muscle quality when compared with the same program performed three times per week in previously-trained elderly men.

Keywords: Exercise, combined training, resistance training, aerobic training, aging

Introduction

The marked reductions in cardiovascular and neuromuscular functions that occur with advancing age[1] can lead to a loss of mobility[2] as well as higher risks of mortality[3] in elderly populations. In addition to the well-established increases in endurance capacity[4], habitual aerobic exercise can minimize several adverse physiological changes associated with aging, particularly arterial stiffening and endothelial dysfunction, and should be used to protect against or reverse these effects[5, 6]. On the other hand, resistance training has been recommended as the first-line strategy to improve age-related loss of skeletal muscle mass, strength, and power[7, 8]. It has been suggested that muscular power is a more discriminant predictor of functional performance in older adults than muscle strength[9]. Considering that leg muscle power is a strong predictor of functional status in the elderly population and is required to perform different daily activities such as walking, climbing stairs, or simply standing from a seated position[10], exercise interventions that enhance muscular power along with aerobic capacity should be highlighted in older adults.

In the scheme of exercise training prescription, training stimuli are gradually augmented by increasing duration and/or frequency as one gets fitter in the exercise training programs. Interestingly, aerobic or resistance training performed exclusively (twice a week) and concurrent training performed with resistance exercise on one day and aerobic exercise on the other day produced similar increases in cardiovascular and neuromuscular parameters in previously untrained elderly men[11]. However, studies evaluating the effects of different frequencies of concurrent training on neuromuscular and cardiovascular functions are limited especially in previously trained older adults[12]. Moreover, there are no data comparing different weekly frequencies of concurrent training on power and muscle quality adaptations in elderly.

Most of the available information come from exercise training intervention studies targeted for previously sedentary populations[4]. Currently, no information is available whether different frequencies would affect training adaptation among older adults who have been regularly exercising. Therefore, the purpose of the present study was to compare the effects of different weekly frequencies of concurrent training on muscular power and muscle quality in previously-trained elderly men. Additionally, in order to analyze the training adaptation more comprehensively, we assessed blood pressure and upper-arm vascular function as secondary outcomes. The operational hypothesis was that concurrent training performed twice a week and three times a week would produce similar muscular adaptations.

Methods

Twenty-four older men, previously engaged in a regular concurrent training program, three times per week, for the previous five months, volunteered for the study. Medical evaluations were performed using health status questionnaire and maximal exercise test with 12-lead electrocardiography. Exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases. Participants were advised to maintain their usual dietary intake throughout the study. Eleven patients were taking blood pressure lowering agents during the study and were asked to maintain their medication use throughout the study. All participants were informed about the study, potential risks and discomforts related to the procedures, and provided written informed consent. This randomized clinical trial was conducted according to Declaration of Helsinki and was approved by the local Institutional Review Board of the institution (protocol number: 120196).

In order to compare the physiological effects of different concurrent training volumes in trained elderly men, we assessed a group who previously participated in 12 weeks of periodized resistance and aerobic training three times per week, performing both exercise types in the same training session[13, 14]. After the first 12 weeks, they performed additional eight weeks of concurrent training, three times per week, at constant volume and intensity (25 min of aerobic training at self-selected intensity and two sets of 10-12 repetitions of resistance training using the load correspondent to 15 repetition maximum - RM) to maintain training adaptations.

Thereafter, participants were enrolled to 10 weeks of concurrent training, and randomly assigned to perform aerobic and resistance training twice a week (2/week; n=12) or to perform aerobic and resistance training three times per week (3/week; n=12). In order to achieve balance across groups, a computer-based randomization list was generated in permuted blocks of size four by an independent collaborator, previously to the beginning of the trial, and maintained outside the clinical scenario. Each subject's weekly training frequency was accessed only on the first day of experimental sessions.

The aerobic and resistance exercises were performed during the same day/session, starting with resistance exercises and immediately followed by the aerobic exercise. The 2/week group trained on Mondays and Fridays, and the 3/week group trained on Mondays, Wednesdays, and Fridays. The resistance training was performed using three sets per exercise at intensities between 6-12 RM. The aerobic training lasted 30 min and was performed at 85-95% of heart rate corresponded to the second ventilatory threshold, which was determined by a maximal incremental exercise test on a cycle ergometer. The concurrent training periodization was used to construct the exercise training programs, as previously described[12]. Despite the differences in the number of training sessions per week, both groups performed the same intensity and volume per session of concurrent training throughout the study. All training sessions were closely supervised by at least 2 experienced personal trainers.

The testing sessions were conducted at the same time, daily. The environmental conditions (e.g., room temperature at 22–24 °C) were kept constant during all tests. This study was part of a larger project, and the data regarding maximal aerobic capacity, maximal strength, and hypertrophy have been published elsewhere[12].

The counter movement jump test was used to evaluate the maximal dynamic power. Using a force platform (OR6-WP, AMTI; Watertown, MA), participants were familiarized to the procedure by performing several jumps in order to learn the correct technique and be able to execute three correct and valid jumps. They were oriented to stand with their feet approximately hip-width apart, hands on their hips and to perform the eccentric and concentric phases at maximum speed, flexing the knee at an angle of approximately 90° before starting the concentric phase. Each participant performed a specific warm-up with 3-5 jumps. Three attempts were executed, with 30-60 seconds of rest intervals between the attempts. The greatest jump height was used for the data analyses and was determined by the equation provided by Asmussen and Bonde-Petersen[15]: jump height=(flight time)2*1.226, using the SAD32 software (Mechanical Measurements Laboratory; UFRGS; Porto Alegre, Brazil). Signal processing included filtering with a fifth-order low-pass Butterworth filter, with a cutoff frequency of

30 Hz. Participants were oriented to use the same sport shoes during the pre and post intervention. The test–retest reliability coefficient was 0.82.

The isokinetic knee extension peak torque was measured at speeds of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ using a Cybex Norm II Isokinetic Dynamometer (Lumex Co, Ronkonkoma, NY). The participants performed a warm-up of 15 submaximal repetitions at $120°\cdot s^{-1}$. Then, maximal sets of five repetitions at the two speeds were performed, with a five min interval between the sets. The contraction with the highest torque value was used in the data analyses.

Muscle quality was evaluated by the quotient between maximal dynamic strength, evaluated through the one-repetition maximal test (1RM) of the knee extensors, and quadriceps femoris muscle thickness, evaluated by ultrasonography. The 1RM was determined with no more than five attempts with a four-minute recovery between attempts. The muscle thickness was determined by the sum of the muscles vastus lateralis, vastus medialis, vastus intermedius and rectus femoris. A detailed description of the 1RM and muscle thickness testing procedures has been described elsewhere[12].

Brachial blood pressure was measured in the dominant arm using a valid calibrated oscillometric automatic device (Dinamap 1846 SX/P; Critikon, FL), in triplicate. Forearm blood flow was measured by venous occlusion plethysmography (D.E Hokanson, Belleview, WA) in the nondominant forearm. A rapid inflator cuff was used in the upper arm to occlude venous outflow (50–60 mmHg), and three blood flow recordings were made each minute for 3 min. During the measurements, blood pressure was measured each minute. After the baseline measurement, reactive hyperemia was evaluated. Blood pressure cuff was inflated to 250 mmHg to institute arterial occlusion for 5 min and was then deflated. Reactive hyperemia was calculated using the peak blood flow after the five-minute occlusion, and forearm vascular resistance was calculated as the mean blood pressure divided by forearm blood flow[16]. All recordings were manually traced by an investigator, who was blinded to the assigned group. Prior to the study, the reproducibility of forearm blood flow measurements was determined in a sample of 10 healthy individuals with intraday and interday coefficients of variation of 6.9 and 9.2%, respectively.

Descriptive data are reported as means±SD. Normal distribution and homogeneity parameters were assessed with Shapiro–Wilk and Levene tests. A t-test was used to compare the load lifted during the strength sessions in each mesocycle. The training-related effects were assessed using a two-way analysis of variance (ANOVA) with repeated measures (group × time). Statistical significance was set at α=0.05, and the SPSS statistical software package (version 17.0) was used to analyze all data.

Results

One participant dropped out from the 2/week group due to personal issues. All the remaining participants completed the protocol and had excellent attendance records (19.7 of 20 sessions (99%) in the 2/week group and 29.1 of 30 sessions (97%) in the 3/week group). The participant's characteristics are shown in Table 1.

******Table 1 here******

Muscle quality, isokinetic muscular torque, and counter movement jump height were similar at the baseline. Both training groups experienced significant increases in muscle quality and counter movement jump height (Figure 1). Isokinetic peak torque at slow velocity ($60°\cdot s^{-1}$) increased significantly in both groups (2/week: 193±30 to 201±37 Nm, and 3/week: 187±30 to 191±19 Nm, p=0.036). Similarly, peak torque at fast velocity ($180°\cdot s^{-1}$) increased in both groups after training (2/week: 125±21 to 134±22 Nm, and 3/week: 123±24 to 124±18 Nm, p=0.014). No significant differences in the magnitudes of improvements between the groups were found.

******Figure 1 here******

Hemodynamics measures are presented in Table 2. There were no significant baseline differences in any of the cardiovascular measures between the groups. Basal forearm blood flow decreased and vascular resistance increased with concurrent training in both groups, with no differences between the groups. Brachial blood pressure and reactive hyperemia did not change with the concurrent training in either group.

******Table 2 here******

Discussion

The primary finding of the study was that the concurrent exercise training performed twice a week produced similar adaptations in muscular power and muscle quality to the concurrent training performed three times per week in previously-trained elderly men. This is in spite of the fact that the overall training volume was substantially lower in the twice a week group. Our present findings may have an important implication for exercise prescription for regularly exercising older adults since relevant increases in muscle power and muscle quality are associated with functional capacity and may be achieved with a lower volume of exercise even in previously-trained individuals.

It has been suggested that muscular power is a more discriminant predictor of functional performance in older adults than muscle strength[9]. The present study demonstrated improvements in both vertical jump and isokinetic peak torque at fast velocity, two important methods to assess lower extremity muscular power in older individuals. Moreover, 2/week and 3/week programs produced similar improvements in muscular power, reinforcing the efficiency of lower frequencies of concurrent training in elderly[12]. Considering that the capacity to perform daily activities, such as walking, climbing stars, and gardening among others, is critical to maintain independent functioning in elderly individuals[9], the present results highlight the efficacy of concurrent exercise training in order to enhancing muscular power in previously-trained elderly men.

Aging is associated with declines in the force per unit of muscle mass (i.e., muscle quality)[17, 18], and declines in muscle quality are associated with reduced functional capacity in elderly populations[17-19]. A recently published study showed associations between muscle quality and functional tasks such as 30-s sit-to-stand, and 8 foot up-and-go after a short-term resistance training in untrained elderly[19]. Our results showed that the simultaneous training for strength and endurance significantly improved muscle quality and that training twice a week or three times a week elicited similar magnitudes of improvements in muscle quality. To the best of our knowledge, this is the first study to investigate the concurrent training effects on muscle quality in previously-trained elderly men.

A recent meta-analysis showed that concurrent training is effective in reducing blood pressure, and the hypotensive effects of exercise were observed after exercise programs with shorter durations[20]. The lack of change in blood pressure and hemodynamic measures, in the present study, may be due to previous training status of participants. Participants were previously trained in both aerobic and strength training, so it is possible that improvements in hemodynamics had already been achieved as hemodynamic changes resulting from exercise training are fairly quick and robust happening in the first few months of training in previously untrained individuals[21].

A previous cross-sectional study showed that strength-trained older individuals demonstrate greater muscle mass and higher basal leg blood flow compared with age-matched sedentary adults[22, 23]. One unexpected finding in the present study was that both groups experienced significant reductions in basal forearm blood flow with the concurrent training in both groups, especially considering that lean body mass, i.e., metabolically active tissue, increased with the concurrent training. However, changes with exercise training were relatively small in magnitude and may be within the measurement error of the plethysmographically-measured forearm blood flow.

The present results bring important exercise prescription implications. Firstly, the combination of resistance and aerobic exercises is beneficial for developing and maintaining neuromuscular and cardiovascular functions in previously-trained elderly. Second, these functional benefits can be achieved even if the concurrent exercise was performed only twice a week. And finally, the use of the current exercise program can help counteracting the marked reductions in the cardiovascular and neuromuscular system that occur with advancing age and improve mobility and function in elderly populations. However, some limitations should be taken into account to interpret the results. Firstly, a non-exercising control group was not included in the study. Second, our sample consisted of men only, therefore limiting the generalization of our findings to the female population. Third, a more comprehensive comparison would have been possible with the inclusion of a once weekly training group (i.e., weekend warriors), which could indicate whether a very low weekly training volume induces improvements in previously-trained older individuals.

Conclusion

In previously-trained older men, concurrent training performed twice a week produces similar responses in muscle power and muscle quality when compared with the same program performed three times per week in elderly men. Our results may have important practical applications in exercise prescription, since the use of lower frequencies of exercise associated with lower amount of time dedicated to exercise, may facilitate the better adherence and compliance in this high risk population.

Practical implications

- The combination of resistance and aerobic exercises (i.e., concurrent training) is beneficial for developing and maintaining neuromuscular and cardiovascular functions in older individuals.
- Twice a week concurrent training is an efficiency strategy to develop muscle power in previously-trained elderly men.
- Different weekly frequencies of training improve mobility and function in elderly populations.
- The combination of resistance and aerobic exercises can help counteracting the marked reductions in the cardiovascular and neuromuscular system that occur with advancing age and improve mobility and function in elderly populations.

Acknowledgements

This study was funded, in part, by scholarships from Brazilian Federal Agency for the Improvement of Higher Education (CAPES) and National Counsel of Technological and Scientific Development (CNPq), and a grant from Hospital de Clínicas de Porto Alegre (FIPE-HCPA: number 120196), RS, Brazil.

The authors declare no duality of interest for the present manuscript.

References

1. Izquierdo M, Hakkinen K, Anton A, et al. Maximal strength and power, endurance performance, and serum hormones in middle-aged and elderly men. *Medicine and science in sports and exercise.* 2001; 33(9):1577-1587.
2. Lauretani F, Russo CR, Bandinelli S, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *Journal of applied physiology.* 2003; 95(5):1851-1860.
3. Lee DC, Sui X, Artero EG, et al. Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men: the Aerobics Center Longitudinal Study. *Circulation.* 2011; 124(23):2483-2490.
4. Mazzeo RS, Tanaka H. Exercise prescription for the elderly: current recommendations. *Sports medicine.* 2001; 31(11):809-818.
5. Santos-Parker JR, LaRocca TJ, Seals DR. Aerobic exercise and other healthy lifestyle factors that influence vascular aging. *Advances in physiology education.* 2014; 38(4):296-307.
6. Seals DR, Desouza CA, Donato AJ, Tanaka H. Habitual exercise and arterial aging. *Journal of applied physiology.* 2008; 105(4):1323-1332.
7. Aagaard P, Magnusson PS, Larsson B, Kjaer M, Krustrup P. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. *Medicine and science in sports and exercise.* 2007; 39(11):1989-1996.
8. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. *Medicine and science in sports and exercise.* 2010; 42(5):902-914.
9. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. *Exercise and sport sciences reviews.* 2012; 40(1):4-12.
10. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *The journals of gerontology. Series A, Biological sciences and medical sciences.* 2000; 55(4):M192-199.

11. Izquierdo M, Ibanez J, K HA, Kraemer WJ, Larrion JL, Gorostiaga EM. Once weekly combined resistance and cardiovascular training in healthy older men. *Medicine and science in sports and exercise.* 2004; 36(3):435-443.

12. Ferrari R, Kruel LF, Cadore EL, et al. Efficiency of twice weekly concurrent training in trained elderly men. *Experimental gerontology.* 2013; 48(11):1236-1242.

13. Cadore EL, Izquierdo M, Alberton CL, et al. Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Experimental gerontology.* 2012; 47(2):164-169.

14. Cadore EL, Izquierdo M, Pinto SS, et al. Neuromuscular adaptations to concurrent training in the elderly: effects of intrasession exercise sequence. *Age.* 2013; 35(3):891-903.

15. Asmussen E, Bonde-Petersen F. Storage of elastic energy in skeletal muscles in man. *Acta physiologica Scandinavica.* 1974; 91(3):385-392.

16. Umpierre D, Stein R, Vieira PJ, Ribeiro JP. Blunted vascular responses but preserved endothelial vasodilation after submaximal exercise in chronic heart failure. *European journal of cardiovascular prevention and rehabilitation.* 2009; 16(1):53-59.

17. Misic MM, Rosengren KS, Woods JA, Evans EM. Muscle quality, aerobic fitness and fat mass predict lower-extremity physical function in community-dwelling older adults. *Gerontology.* 2007; 53(5):260-266.

18. Granacher U, Gruber M, Gollhofer A. Force production capacity and functional reflex activity in young and elderly men. *Aging clinical and experimental research.* 2010; 22(5-6):374-382.

19. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. *Age.* 2014; 36(1):365-372.

20. Cornelissen VA, Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. *Journal of the American Heart Association.* 2013; 2(1):e004473.

21. DeSouza CA, Shapiro LF, Clevenger CM, et al. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. *Circulation.* 2000; 102(12):1351-1357.

22. Anton MM, Cortez-Cooper MY, DeVan AE, Neidre DB, Cook JN, Tanaka H. Resistance training increases basal limb blood flow and vascular conductance in aging humans. *Journal of applied physiology*. 2006; 101(5):1351-1355.

23. Miyachi M, Tanaka H, Kawano H, Okajima M, Tabata I. Lack of age-related decreases in basal whole leg blood flow in resistance-trained men. *Journal of applied physiology*. 2005; 99(4):1384-1390.

Table 1: Characteristics of the participants [mean ±SD or absolute frequency]

	2/week (n=11)		3/week (n=12)	
	Pre-training	Post-training	Pre-training	Post-training
Age, y	63.2 ± 2.2	-	65.7 ± 5.7	-
Height, m	1.75 ± 0.6	-	1.69 ± 0.3	-
Body mass, kg	81.4 ± 10.5	80.9 ± 10.2	76.1 ± 6.3	75.9 ± 7.6
Body fat, %	27.8 ± 2.5	25.8 ± 3.7	26.2 ± 2.9	25.2 ± 2.6
VO_{2peak}, $l.min^{-1}$	1.9±0.4	2.2±0.4*	1.9±0.4	2.1±0.3*
Anti-hypertensive Medications (n)	6	6	5	5

Data are means ± SD. $VO2_{peak}$=peak oxygen consumption; Strength-endurance twice a week group (2/week) and strength-endurance three times a week group (3/week). *p<0.01 vs Pre

Table 2: Forearm hemodynamics and blood pressure with concurrent training

	2/week		3/week	
	Pre-training	Post-training	Pre-training	Post-training
FBF, $ml.100ml^{-1}.min^{-1}$	3.2 ± 0.5	2.7 ± 0.8*	3.4 ± 0.6	3.0 ± 0.7*
FVR, U	29.8 ± 5.1	35.6 ± 7.7*	28.9 ± 7.8	33.9 ± 7.3*
RH, $ml.100ml^{-1}.min^{-1}$	10.6 ± 1.6	9.7 ± 3.2	10.5 ± 2.4	10.7 ± 2.9
Systolic BP, mm Hg	123 ± 18	123 ± 15	132 ± 17	137 ± 14
Diastolic BP, mm Hg	75 ± 9	76 ± 9	73 ± 10	76 ± 9
Mean BP, mm Hg	91 ± 10	92 ± 11	92 ± 11	95 ± 10

Data are means ± SD; FBF, forearm blood flow; FVR, forearm vascular resistance; RH, reactive hyperemia; BP, blood pressure. Strength-aerobic twice a week group (2/week) and strength-aerobic three times a week group (3/week). *P<0.01 *vs.* Pre

Figure

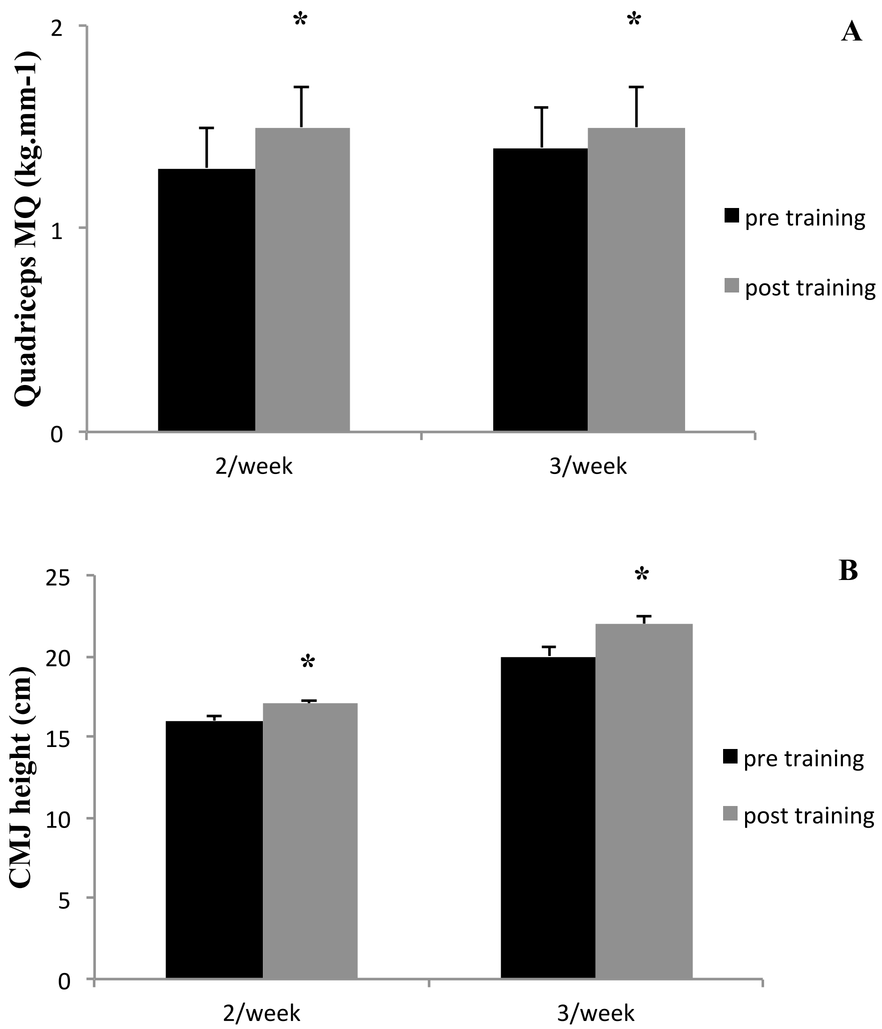

Fig 1: Changes in Muscle Quality (MQ) (A) and Countermovement jump (CMJ) height (B) with concurrent exercise training. Resistance-aerobic twice a week group (2/week) and resistance-aerobic three times a week group (3/week). Values are means ± SEM. * $P<0.05$ vs. Pre

Effects of different exercises on post-exercise blood pressure in elderly hypertensive men: A crossover randomized clinical trial

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Acknowledgements

This study was funded, in part, by scholarships from Brazilian Federal Agency for the Improvement of Higher Education (CAPES) and National Counsel of Technological and Scientific Development (CNPq), and a grant from Hospital de Clínicas de Porto Alegre (FIPE-HCPA: n°130484), RS, Brazil.

Abstract

PURPOSE: Based on the lack of evidence evaluating the effects of a single session of concurrent training on post-exercise hypotension (PEH) in elderly hypertensive subjects, the purpose of the present study was to compare the effects of different types of exercise on post-exercise blood pressure in hypertensive elderly men. METHODS: Twenty elderly hypertensive men, not engaged in a regular exercise program on the last 3 months, were enrolled for the study. They completed three experimental protocols in a randomized order: a non-exercise control session (C) and two exercise bouts, one of aerobic exercise (AE) and another of concurrent resistance and aerobic exercise (RAE). All experimental sessions will start at 9:00AM and last approximately 2h10min. At the beginning of each session, the subjects rested for 20 min and had their blood pressure (BP) measured. After that, they performed 45 min of AE (65-70% of the heart rate reserve - HRR), RAE (4 sets at 70% 1RM of resistance exercise followed by AE) or C (no exercise at seated rest). After each intervention, the BP was measured continuously for 1h in laboratory and for 24h under ambulatory conditions. RESULTS: During the first hour in laboratory, diastolic BP was lower after AE (-4.5 mmHg - CI95%: -9.0 – -0.2 mmHg; p=0.049) and RAE (-5.9 mmHg - CI95%: -10.8 – -0.94 mmHg; p=0.017) in comparison with C. Systolic BP presented reduced values with borderline significance after AE (-6.7 mmHg - CI95%: -13.9 – 0.4 mmHg; p=0.069) and RAE (-6.3 mmHg - CI95%: -13.2 – 0.63 mmHg; p=0.082) in comparison with C. Daily diastolic ambulatory BP was significantly lower after AE when compared to the C (-6.8 mmHg - CI95%: -10.9 – -2.8 mmHg; p<0.001) and RAE (-3.9 mmHg - CI95%: -8.1 – 0.2 mmHg; p=0.067). No significant differences were found among the three experimental sessions for nightly and 24h diastolic ambulatory BP, as well as daily, nightly and 24h systolic ambulatory BP. CONCLUSION: AE and RAE reduced BP in laboratory for 1h after exercise, but only AE sustained this reduction throughout the day under usual conditions.

Introduction

Hypertension is a major risk factor for developing cardiovascular disease and it's prevalence among the elderly population in Brazil is approximately 68% (IC95%: 65.1-69.4%) [1]. Regular exercise is an effective non-pharmacological treatment able to reduce arterial blood pressure (BP) in hypertensive elderly individuals[2-5]. The chronic reduction in BP following different exercise protocols may be result from the additive hypotensive effects that occur in the hours following the workout [6]. The post-exercise hypotension (PEH) resulting from a single session[7] has been investigated in several populations [2, 6, 8]. However, in order to obtain clinical relevance, the PEH should achieve at least a few mmHg and be sustained for some time in usual conditions [9].

In elderly hypertensive individuals, several exercise protocols have been performed in order to evaluate their effects on PEH. Significant decreases were observed in 24h systolic and diastolic ambulatory blood pressure monitoring (ABPM) after 45 minutes of aerobic exercise at moderate (i.e., 50% VO_{2max}) [10] and high intensity (i.e., 70% VO_{2max}) [2]. On the other side, different volumes of resistance exercise (i.e., 1 and 3 sets) reduced BP during 90 min after exercise with more pronounced effects obtained in the session with higher volume [11]. Although such studies have been conducted in the elderly population, the effects of resistance training on BP measured by 24h ABPM are scarcely reported and should be further investigated.

The combination of resistance and aerobic exercises (i.e., concurrent training) is the most effective strategy to improve both neuromuscular and cardiovascular responses in elderly individuals[12]. Nevertheless, there are few studies evaluating the effects of concurrent training sessions on PEH [6] and it is not clear if a single session of concurrent training is an efficacious strategy to reduce BP in hypertensive elderly individuals[5]. In addition, it remains uncertain the duration of the effects of a single session of concurrent training on PEH measured by 24h ABPM among elderly hypertensive individuals. Therefore, the purpose of the present study was to compare the effects of different types of exercise on post-exercise blood pressure among hypertensive elderly men. The hypothesis was that concurrent exercise would produce higher post-exercise blood pressure responses and lower 24h systolic and diastolic BP, measured by ABPM when compared to the control group and that it would be equally efficacious as the aerobic exercise to reduce blood pressure at the first laboratory hour and on 24h systolic and diastolic BP, measured by ABPM.

Methods

Participants

Twenty men, aged 60 to 70 years, with previous physician diagnosis of hypertension and not engaged in regular exercise programs in the last three months, who volunteered to took part of the study. Participants were informed about the study and signed a consent form. The study protocol was conducted according to the Declaration of Helsinki, it was approved by the Institutional Review Board (protocol number: 130484) of our institution, and registered on clinicaltrials.gov (NCT 02415582). The exclusion criteria included smoking, physical limitation to perform resistance or endurance exercises, BMI ≥ 30 kg/m^2, and non-controlled blood pressure (i.e. SBP > 160 mmHg or DBP > 110 mmHg).

Study design and procedures

A crossover randomized trial was performed in order to evaluate the effects of different exercises on BP. Figure 1 shows the study design. Participants were randomized to three experimental protocols: a non-exercise control session of seated rest and two exercise bouts, one of aerobic exercise and another of combined resistance, and a session of aerobic exercise. A washout period of 7 days between each intervention was adopted. All experiments were conducted at the same time of day to account for diurnal variation in BP.

Figure 1 here

During the run in period each participant performed a cardiopulmonary testing and a strength test in two separated days, and the results of these tests were used to prescribe the exercise intensity. The strength was assessed using the one maximum repetition test (1RM) on the bilateral elbow flexors, bench press, bilateral knee flexors and bilateral knee extensors. The subjects warmed up for 5 min on a cycle ergometer, stretched all major muscle groups, and performed specific movements with 1 set of 15 repetitions with light load (30% of the first test load) in the exercise tests. Each subject's maximal load was determined with no more than five attempts with a five-minute recovery between sets. Each contraction (concentric and eccentric) lasted 1,5 seconds, and was controlled by an electronic metronome (Quartz, CA, USA). In order to determine the peak oxygen consumption (VO_{2peak}) and maximal heart rate (HR_{max}), an incremental test on a treadmill was performed. The protocol consisted of an initial velocity of 3,5 km.h^{-1} with 1% inclination during 2 min. After this, the velocity and grade were increased every 1 min until the subjects reached their maximal effort. The expired gas was analyzed using a metabolic cart (Oxycon Delta, VIASYS, Healthcare GmbH, Jaeger, Germany) breath by breath. BP, ECG and HR were continuously monitored and registered throughout the test. The maximum VO_2 value ($ml \cdot kg^{-1} \cdot min^{-1}$) obtained close to exhaustion was considered the Peak Oxygen Uptake (VO_{2peak}). The incremental test was conducted in the presence of a physician.

Experimental protocols

Participants performed three experimental sessions in a randomized order: aerobic exercise session (AE), concurrent resistance and aerobic exercise session (RAE), and a control session (C) without any exercise. All experimental sessions started 9:00 AM and lasted approximately 2h 10min.

At the beginning of each session, the subjects rested in the seated position for 20 min and underwent to standardized BP measurement in the dominant arm, in triplicate, and the first measurement was excluded. At the laboratory, BP measurements were made using a calibrated oscillometric automatic device (Dinamap 1846 SX/P; Critikon, Florida, USA) Magazines were available during the rest periods throughout the study.

The AE was performed on a treadmill during 45 min at the intensity corresponding to 65-70% of the heart rate reserve (HRR). The HR was monitored throughout the session in order to maintain the intensity of exercise with adjustments of velocity or grade, if necessary. The RAE was composed by 20 min of resistance exercises followed by 25 min of aerobic exercise at 65-70% HRR. The resistance exercise was composed by 4 sets of each exercise at 70% 1RM and performed in the following sequence: bench press, bilateral knee extensors, bilateral elbow flexors, and bilateral knee flexors. These exercises were grouped in two blocks, in which the sets of the second exercise were performed during the rest of the first. An active interval of 2 min was allowed between sets in each exercise. At the control session, the subjects rest at seated position during 45 min, without any exercise.

During the first hour after each intervention, the BP was measured continuously at seated position and registered every 5 minutes during 1h, using oscillometric device, in our laboratory. Afterwards, participants underwent 24-h ABPM using a monitor (Spacelabs 90207; Spacelabs Inc., Healthcare, Redmond, Washington, USA) programmed to take measurements every 15 min from 11:00 AM to 22:00 PM and every 20 min from 10:00 PM to 06:00 AM. The analysis of ABPM readings were performed according to the guidelines of European Society of Hypertension [13].

Participants were advised to maintain similar activities on the day before the sessions, during the 24h ABPM, and after the experimental sessions. Moreover, they were instructed to avoid exercise and to keep usual dietary intake throughout the study. Participants who were taking antihypertensive lowering medications were requested to maintain their current treatment during the trial, which were not modified in the follow-up visits. Whether there was any change in medication use throughout the study, they were instructed to report it.

Randomization and allocation

The randomization was performed using random block sizes of six, previously to the starting of the study, by an independent investigator, and the order of the sessions and the sequence was concealed to the research team. The subject's order was accessed (telephone central) only at the first day of experimental sessions.

Participants and investigators were blinded regarding the order of exercise sessions and the sequence of randomization. At each enrolment, since the eligibility criteria were confirmed, the order of the exercise sessions became progressively disclosed to the investigator and participant.

Statistical analysis

Results were reported as mean ± SD for normally distributed data, which were checked using the Shapiro-Wilk test. Statistical comparisons throughout the interventions were tested using two-way analysis of variance ANOVA for repeated measures, with sessions (C, AE, and RAE) and time (pre, post 1 hour, total awake, total asleep and 24h after exercise) as main factors. Statistical significance was accepted when $P < 0.05$ and a trend toward significance was detected for P values ranging from 0.05 to 0.10. The SPSS statistical software package (version 22.0, IBM corp., New York, USA) was used to analyze the data.

Results

Study Participants

A total of 22 participants were enrolled in the trial, two withdraw the consent form previously to the first session of exercise, and one participant did not complete the ABPM assessment after the control session (Figure 2).

Table 1 shows that participants had on average of 65.3 ± 3.3 years, BMI of overweight, and had average cardiorespiratory fitness and strength levels. Most participants (95%) were on antihypertensive lowering medication, receiving one (35%), two (60%) or three (5%) agents. Participants reported no change in antihypertensive treatment.

Figure 2 here

Table 1 here

BP responses throughout the experimental sessions

Table 1 shows that baseline BP was within normal range. Figure 3 describes the average systolic and diastolic BP responses one hour after the experimental sessions under laboratory conditions. A significant interaction was found for diastolic BP (P=0.02) and a trend towards significance was observed for the interaction of exercise sessions on systolic BP (P=0.067). Diastolic BP was lower after AE (-4.5 mmHg; CI95%: -9.0 to -0.2 mmHg; P=0.049) and RAE (-5.9 mmHg; CI95%: -10.8 to -0.94 mmHg; P=0.017) in comparison with Control. There was a trend toward reduction of systolic BP after AE (-6.7 mmHg; CI95%: -13.9 to 0.4 mmHg; P=0.069) and RAE (-6.3 mmHg; CI95%: -13.2 to 0.63 mmHg; P=0.082) in comparison to Control.

In relation to baseline, systolic BP decreased after AE (-5.1 mmHg; CI95%: -8.2 to -2.0 mmHg; P=0.003) and RAE (-4.7 mmHg; CI95%: -8.0 to -1.3 mmHg; P=0.008), whereas no significant change after the Control session was found (1.6 mmHg; CI95%: -2.8 to 6.0 mmHg; P=0.457). Diastolic BP did not change after AE (-1.9 mmHg; CI95%: -4.3 to 0.4 mmHg; P=0.099), decreased after RAE (-3.3 mmHg; CI95%: -6.5 to -0.8 mmHg; P=0.036), whereas rose after Control session (2.6 mmHg; CI95%: 0.4 to 5.1 mmHg; P=0.051).

Figure 3 here

Ambulatory BP responses

Daily diastolic BP was significantly lower after AE when compared to the Control (-6.8 mmHg; CI95%: -10.9 to -2.8 mmHg; P <0.001) and a borderline significance compared to RAE (-3.9 mmHg; CI95%: -8.1 to 0.2 mmHg; P=0.067). No significant differences were found among the three experimental sessions for nightly and 24h diastolic BP, as well as daily, nightly and 24h systolic BP (Table 2).

Table 2 here

Discussion

To the best of our knowledge, this is the first trial evaluating BP responses after aerobic and concurrent exercises in elderly hypertensive men. This trial found that both exercises reduced BP during the first hour after the exercise sessions in comparison to the control session, but only aerobic exercise sustained the reduction throughout the day.

We found a reduction of 7 mmHg in daily diastolic BP after AE in comparison to Control session. Previous studies assessing the effect of acute aerobic exercise on 24h diastolic BP have found reductions of approximately 4 mmHg [10, 14] or even no difference from the control group [15]. In those studies, participants had higher baseline BP than it was observed in the present study. Therefore, greater reductions in diastolic BP would be expected in those with higher baseline BP [16]. However, our aerobic protocol was able to achieve higher reduction on daily diastolic BP in hypertensive men. Considering that BP is directly related to vascular and overall mortality and reduction of 5 mm Hg of DBP is associated with 40% lower risk of death [17], our result has important clinical relevance to the elderly population.

As previously reported [6, 18], this trial found significant reductions in laboratory systolic and diastolic BP after concurrent exercise. Although the mechanisms underlying PEH were not evaluated in the present study, we believe that those reductions are due to a decrease in stroke volume, leading to a reduction in cardiac output that was not compensated by an increase in systemic vascular resistance [2, 19]. However, in contrast to our hypothesis and in agreement with a previous study [20], concurrent exercise did not reduce systolic or diastolic BP, measured by ABPM, in comparison to the control session. We can only speculate on distinct responses regarding the exercise modes. One session of high intensity resistance exercise (i.e., 70%1RM) decreases maximal strength and power over 72h after session [21]. It is possible that the residual fatigue resulted from high intensity resistance exercise rose the cardiovascular stress during daily activities of the participants, impairing the potential PEH of aerobic exercise when performed simultaneously to resistance exercise.

The absence of differences between the exercise and the control sessions for 24h, daily and nightly systolic BP could be justified by the lower BP at the pre intervention, which was explained by the use of anti-hypertensive lowering medications and controlled hypertension throughout the study. The magnitude of the BP reduction after exercise sessions is directly related to the pre intervention BP of participants [16, 22], and this fact could explain the absence of differences among the exercises interventions and the control session found in our study.

This study shows novelty that can have an impact on exercise prescription for the elderly population. Firstly, the combination of resistance and aerobic exercises reduces BP during the first hour after exercise, but not for longer periods of time. Second, aerobic exercise should be performed as the first line intervention in order to decrease BP. Finally, even those patients who have controlled BP, exercise seems to be an effective strategy to reduce BP during the hours after exercise cessation. However, some limitations should be taken into account in order to interpret the results. A resistance session only was not included in the study. Moreover, our sample consisted of men only, therefore limiting the generalization of our findings to the female population.

In conclusion, the present study shows that aerobic and concurrent exercise are able to reduce BP under laboratory conditions, but only aerobic exercise sustains the reduction throughout the day. From a practical standpoint, although concurrent exercise is the most effective strategy to improve both neuromuscular and cardiovascular functions in elderly, programs using aerobic exercises should be prioritized in order to prolong the PEH in hypertensive elderly men.

Table 1: Characteristics of the participants [mean ±SD or absolute frequency]

	n=20
Age, yr	65.3 ± 3.3
Height, m	1.70 ± 0.1
Body mass, kg	81.0 ± 7.8
BMI, kg/m^2	27.7 ± 1.8
VO_{2max} , $ml.kg^{-1}.min^{-1}$	32.6 ± 4.6
HR_{max} , bpm	145.3 ± 23.0
1 RM Bench press, kg	44.9 ± 9.0
1 RM Arm curl, kg	26.5 ± 4.2
1 RM Knee extension, kg	108.7 ± 19.5
1 RM Knee Flexion, kg	50.5 ± 8.2
Systolic blood pressure, mmHg	119.7 ± 13.2
Diastolic blood pressure, mmHg	70.9 ± 9.9
Antihipertensive lowering medications	
β-Blockers	2
CCB	1
Diuretics	1
ACE inhibitor or ARA II	4
Diuretics + CCB	3
CCB^+ + β-Blockers	1
β-Blockers + ACE inhibitor	1
CCB + ARA II	2
Diuretics + β-Blockers + ACE inhibitor	1
Diuretics + CCB + ARA II	1

ACE inhibitor: Angiotensin-converting-enzyme inhibitor

ARA II: Antagonistas do receptor da angiotensina II

CCB: Calcium channel blockers

Table 2: Ambulatory blood pressure monitoring pre and post interventions and the corresponding deltas

					P values		
Blood pressure	Intervention	Pre	Post	Delta (mmHg)	Time	Intervention	Interaction
24-h systolic	AE	118.4±10.3	124.9±8.2	6.3±7.5	0.001	0.067	0.672
	RAE	122.1±9.8	127.1±9.4	5.3±6.9			
	C	119.7±13.2	126.1±9.8	6.5±9.0			
Daily systolic	AE	118.4±10.3	129.0±7.8	10.7±7.9	0.001	0.098	0.488
	RAE	122.1±9.8	131.3±9.5	9.1±8.2			
	C	119.7±13.2	132.1±9.3	12.4±8.7			
Nightly Systolic	AE	118.4±10.3	117.3±9.3	1.0±9.5	0.146	0.578	0.329
	RAE	122.1±9.8	120.3±11.6	1.6±8.1			
	C	119.7±13.2	116.3±12.7	3.4±12.1			
24-h diastolic	AE	72.3±10.1	73.6±7.7	2.7±4.8	0.002	0.199	0.697
	RAE	73.7±9.1	75.5±8.5	3.3±4.6			
	C	70.9±9.9	74.6±8.9	3.7±6.4			
Daily diastolic	AE	72.3±10.1	74.1±7.7*	1.8±4.3	0.001	0.004	0.001
	RAE	73.7±9.1	79.6±7.7	5.9±6.8			
	C	70.9±9.9	79.7±8.6	8.8±6.2			
Nightly diastolic	AE	72.3±10.1	67.7±9.3	3.1±7.2	0.766	0.470	0.178
	RAE	73.7±9.1	69.4±10.1	2.8±6.8			
	C	70.9±9.9	67.3±10.3	3.5±8.4			

Data are mean ± SD. Blood pressure (mmHg); AE, aerobic exercise; RAE, resistance and aerobic exercise; C, control session; * Different from C and RAE

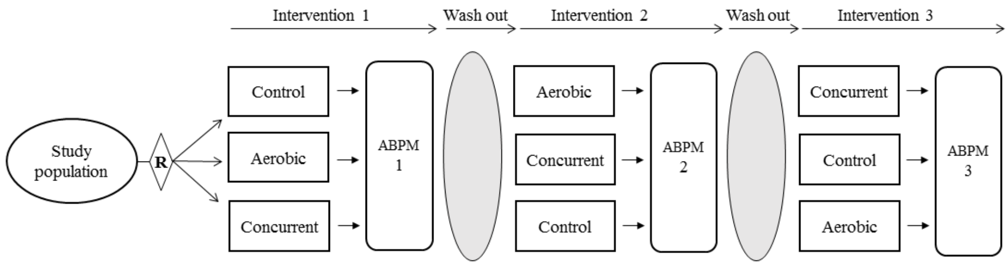

Figure 1. Study design overview

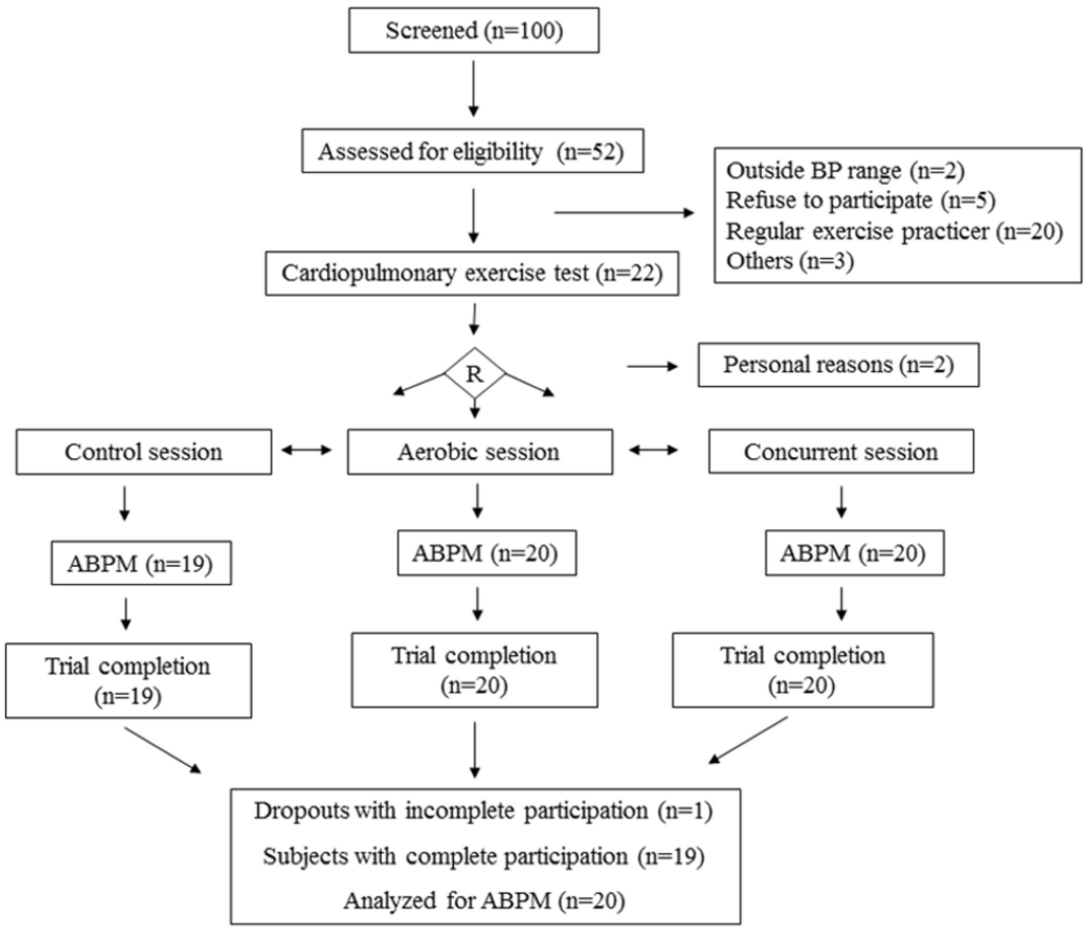

Figure 2. Flowchart of participants

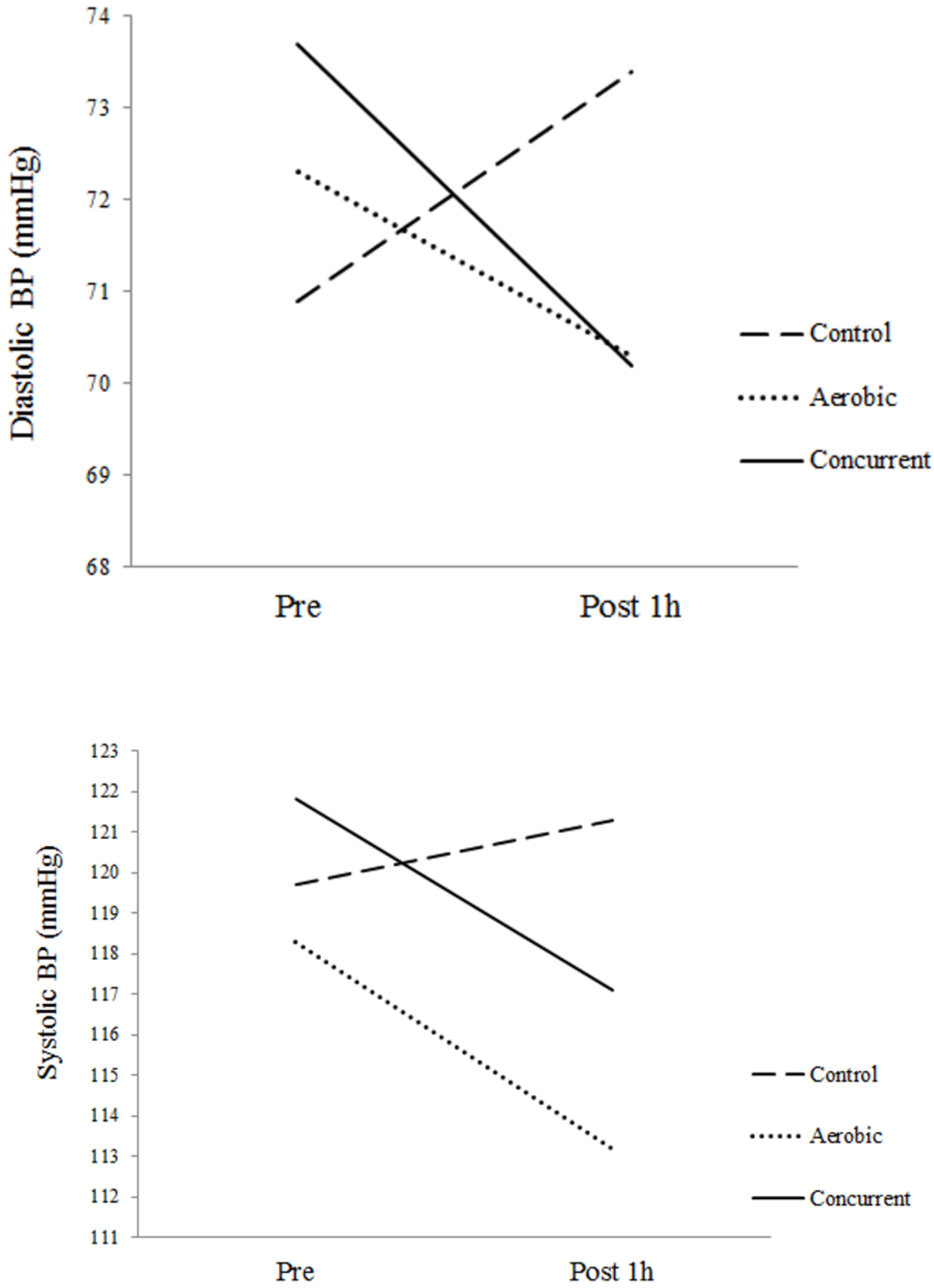

Figure 3. Systolic and diastolic blood pressure pre and post intervention, which shows the average for the first hour after each experimental protocol.

References

1. Picon RV, Fuchs FD, Moreira LB, Fuchs SC. Prevalence of hypertension among elderly persons in urban Brazil: a systematic review with meta-analysis. American journal of hypertension. 2013; 26 (4):541-8.

2. Brandao Rondon MU, Alves MJ, Braga AM, Teixeira OT, Barretto AC, Krieger EM, et al. Postexercise blood pressure reduction in elderly hypertensive patients. Journal of the American College of Cardiology. 2002; 39 (4):676-82.

3. Sillanpaa E, Hakkinen A, Punnonen K, Hakkinen K, Laaksonen DE. Effects of strength and endurance training on metabolic risk factors in healthy 40-65-year-old men. Scandinavian journal of medicine & science in sports. 2009; 19 (6):885-95.

4. Moraes MR, Bacurau RF, Casarini DE, Jara ZP, Ronchi FA, Almeida SS, et al. Chronic conventional resistance exercise reduces blood pressure in stage 1 hypertensive men. Journal of strength and conditioning research / National Strength & Conditioning Association. 2012; 26 (4):1122-9.

5. Cornelissen VA, Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. Journal of the American Heart Association. 2013; 2 (1):e004473.

6. Keese F, Farinatti P, Pescatello L, Monteiro W. A comparison of the immediate effects of resistance, aerobic, and concurrent exercise on postexercise hypotension. Journal of strength and conditioning research / National Strength & Conditioning Association. 2011; 25 (5):1429-36.

7. Kenney MJ, Seals DR. Postexercise hypotension. Key features, mechanisms, and clinical significance. Hypertension. 1993; 22 (5):653-64.

8. Eicher JD, Maresh CM, Tsongalis GJ, Thompson PD, Pescatello LS. The additive blood pressure lowering effects of exercise intensity on post-exercise hypotension. American heart journal. 2010; 160 (3):513-20.

9. Cardoso CG, Jr., Gomides RS, Queiroz AC, Pinto LG, da Silveira Lobo F, Tinucci T, et al. Acute and chronic effects of aerobic and resistance exercise on ambulatory blood pressure. Clinics. 2010; 65 (3):317-25.

10. Taylor-Tolbert NS, Dengel DR, Brown MD, McCole SD, Pratley RE, Ferrell RE, et al. Ambulatory blood pressure after acute exercise in older men with essential hypertension. American journal of hypertension. 2000; 13 (1 Pt 1):44-51.

11. Brito Ade F, de Oliveira CV, Brasileiro-Santos Mdo S, Santos Ada C. Resistance exercise with different volumes: blood pressure response and forearm blood flow in the hypertensive elderly. Clinical interventions in aging. 2014; 9:2151-8.

12. Ferrari R, Kruel LF, Cadore EL, Alberton CL, Izquierdo M, Conceicao M, et al. Efficiency of twice weekly concurrent training in trained elderly men. Experimental gerontology. 2013; 48 (11):1236-42.

13. O'Brien E, Parati G, Stergiou G, Asmar R, Beilin L, Bilo G, et al. European Society of Hypertension position paper on ambulatory blood pressure monitoring. Journal of hypertension. 2013; 31 (9):1731-68.

14. Pescatello LS, Fargo AE, Leach CN, Jr., Scherzer HH. Short-term effect of dynamic exercise on arterial blood pressure. Circulation. 1991; 83 (5):1557-61.

15. Guidry MA, Blanchard BE, Thompson PD, Maresh CM, Seip RL, Taylor AL, et al. The influence of short and long duration on the blood pressure response to an acute bout of dynamic exercise. American heart journal. 2006; 151 (6):1322 e5-12.

16. Queiroz AC, Sousa JC, Cavalli AA, Silva ND, Jr., Costa LA, Tobaldini E, et al. Post-resistance exercise hemodynamic and autonomic responses: Comparison between normotensive and hypertensive men. Scandinavian journal of medicine & science in sports. 2015; 25 (4):486-94.

17. Lewington S, Clarke R, Qizilbash N, Peto R, Collins R, Prospective Studies C. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet. 2002; 360 (9349):1903-13.

18. Meneses AL, Forjaz CL, de Lima PF, Batista RM, Monteiro Mde F, Ritti-Dias RM. Influence of endurance and resistance exercise order on the postexercise hemodynamic responses in hypertensive women. Journal of strength and conditioning research / National Strength & Conditioning Association. 2015; 29 (3):612-8.

19. Teixeira L, Ritti-Dias RM, Tinucci T, Mion Junior D, Forjaz CL. Post-concurrent exercise hemodynamics and cardiac autonomic modulation. European journal of applied physiology. 2011; 111 (9):2069-78.

20. Terblanche E, Millen AM. The magnitude and duration of post-exercise hypotension after land and water exercises. European journal of applied physiology. 2012; 112 (12):4111-8.

21. Ide BN, Leme TC, Lopes CR, Moreira A, Dechechi CJ, Sarraipa MF, et al. Time course of strength and power recovery after resistance training with different movement velocities. Journal of strength and conditioning research / National Strength & Conditioning Association. 2011; 25 (7):2025-33.

22. Melo CM, Alencar Filho AC, Tinucci T, Mion D, Jr., Forjaz CL. Postexercise hypotension induced by low-intensity resistance exercise in hypertensive women receiving captopril. Blood pressure monitoring. 2006; 11 (4):183-9.

7. CONCLUSÕES E CONSIDERAÇÕES FINAIS

O crescimento exponencial de indivíduos idosos traz consigo a busca por estratégias que promovam um envelhecimento mais saudável para essa população. Com base nos achados da presente tese e nas diferentes pesquisas sobre os benefícios do EF na independência, qualidade e expectativa de vida das pessoas mais velhas, é essencial o desenvolvimento de políticas públicas que utilizem o EF como ferramenta de combate aos diferentes processos deletérios associados ao envelhecimento.

Cronicamente, o treinamento concorrente realizado em baixa frequência semanal é um modelo de exercício eficiente para idosos que buscam desenvolver diferentes parâmetros cardiovasculares e neuromusculares, tais como: força, potência, massa muscular e consumo de oxigênio. De forma aguda, diferentes modelos de exercício físico reduzem a pressão arterial em condições laboratoriais, porém o exercício aeróbio é o modelo que sustenta essa redução por um período mais prolongado em homens idosos hipertensos.

Embora os resultados dos dois ensaios clínicos apresentados tragam novas informações referentes os benefícios que o exercício aeróbio combinado ao exercício de força em idosos, novas pesquisas investigando a eficiência desse modelo de exercício nas diferentes variáveis que contribuem para a independência funcional do idoso são necessárias. Comparação de diferentes frequências de treinamento, relação dose-resposta para redução de pressão arterial, efeitos de longo prazo (i.e., mais de 1 ano de intervenção), aderência da população idosa ao EF, entre outros, devem ser explorados em futuros estudos sobre o tema.