REVIEW

ACCEPTED: June 2020

PUBLISHED ONLINE: March 2021

Kibele A, Claußen L, Eckart N. Why resistance training in metastable states of equilibrium could be beneficial for older adults – a narrative review. Dtsch Z Sportmed. 2021; 72: 54-60. doi:10.5960/dzsm.2020.442

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Why Resistance Training in Metastable States of Equilibrium Could Be Beneficial for Older Adults – A Narrative Review

Warum ein Krafttraining in metastabilen Gleichgewichtslagen für ältere Menschen nützlich sein könnte – ein narratives Review

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Summary

› **Using resistance training** on unstable supports or with instability devices athletes aim to prepare their neuromuscular system for sudden and unforeseen impairments in equilibrium impeded by the environment or through sports partners. In contrast to athletes, older adults aim to avoid such situations impeded by instability to reduce a possible risk of falling.

› **The goal of this review** is to outline the specific benefits of resistance training on unstable supports or with instability devices, denote as metastability resistance training (MRT), in older adults while extending knowledge of past reviews in this field.

› **Existing studies** comparing MRT to traditional resistance training (RT) on stable surfaces are reviewed and summarized. Our review shows that MRT: a) is safe for the older adult when properly introduced and supervised; b) requires smaller training loads and stresses larger articular areas while providing similar or larger gains in strength as traditional RT on stable surfaces; c) provides extended gains in functional mobility, balance, and power; d) offers a strengthening of stabilizer muscles whose strength loss is assumed to facilitate falls; e) stabilizes gait performance and, thus, reduces the risk of falls; f) improves cognitive performance reducing reductions the fear of falling and improves executive functions.

› **Moreover**, MRT was found to be particularly beneficial for Parkinson's disease patients. Hence, MRT could be a very useful tool to complement the physical conditioning of older adults.

Zusammenfassung

› **Durch die Nutzung von Krafttraining** auf instabilen Unterlagen oder mit instabilen Geräten beabsichtigen Leistungssporttreibende, ihr neuromuskuläres System auf unerwartete Störungen des Körpergleichgewichts im Sport durch Umweltbedingungen oder Sportpartner vorzubereiten. Im Gegensatz zum Leistungssport versuchen ältere Menschen instabile Körpergleichgewichtslagen zu vermeiden, um ein mögliches Sturzrisiko auszuschließen.

› **Dieses Review hat zum Ziel,** den spezifischen Nutzen eines Krafttrainings auf instabilen Unterlagen oder mit instabilen Geräten, das als Metastabilitätskrafttraining (MKT) bezeichnet wird, für ältere Menschen aufzuzeigen.

› **Dazu werden Studien** aus der Fachliteratur recherchiert und analysiert, die ein MKT einem herkömmlichen Krafttraining (KT) gegenüberstellen. Es wird dabei herausgestellt, dass MKT: a) für den Einsatz bei älteren Menschen sicher ist, sofern es systematisch eingeführt und überwacht wird; b) bei vergleichbar großen Kraftzuwächsen weniger hohe Lasten erfordert und größere Gelenkflächen beansprucht als ein KT auf stabilen Unterlagen; c) größere Verbesserungen in der funktionellen Mobilität, dem Gleichgewichtsvermögen und der Schnellkraft herbeiführt; d) eine Möglichkeit zur Kräftigung der stabilisierenden Muskulatur bietet, deren Kraftverlust mit einem höheren Sturzrisiko in Verbindung steht; e) eine Stabilisierung des Gangverhaltens bewirkt und daher gleichfalls vor Stürzen schützt; f) die kognitive Leistungsfähigkeit optimiert und dabei die Angst, zu stürzen, vermindert sowie die exekutiven Funktionen verbessert.

› **Zudem** hat sich ein MKT auch bei Parkinsonpatienten bewährt. Ein solches Training könnte daher eine wichtige Ergänzung in Körperertüchtigungsprogrammen von älteren Menschen darstellen.

KEY WORDS:
Instability Resistance Training, Metastability, Fall Prevention, Fear of Falling

SCHLÜSSELWÖRTER:
Instabilitäts-Widerstandstraining, Metastabilität, Sturzprävention, Sturzangst

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Introduction

Mild to severe conditions of instability are common to situations in sports including duels in team sports, slippery surfaces during rainy days in outdoor activities, or wind and waves during water sports. Therefore, athletes prepare themselves through, what has been called, instability resistance training (IRT). Related exercises encompass, for example, lifting loads on unstable platforms as inflatable discs, tilting boards, swiss balls, bosu balls, or loads with instability devices as water filled tubes or suspended weights attached to barbells (23). Using IRT, athletes aim to adapt their neuromuscular system to sudden and unforeseen changes in equilibrium impeded by instability. In contrast to athletes, older adults tend to avoid any situation impeded by instability to reduce a possible risk of falling. So, why should IRT

be beneficial for older adults? Noteworthy, IRT has not been suggested, or even mentioned, for older adults in position statements of strength and conditioning associations (17). In 2015, a systematic review and meta-analysis on the effects of IRT on strength, power, and balance performance across the lifespan by Behm and coworkers (3) identified three relevant studies in older adults. Overall, no effects to medium IRT effects in maximal strength, small effects on muscle power, and large IRT effects on static and dynamic balance were found. While two of the three studies (6, 39) examined IRT effects on balance, only one study (19) analyzed IRT improvements in muscle strength. For the latter investigation, improvements in the isometric strength of core muscles through IRT were detected as compared to a passive control group.

This article aims to extend the study results for older adults in a previous IRT review by Behm and colleagues (3) by more recent studies with active control groups including various age-specific IRT effects. For example, studies comparing IRT to conventional resistance training (RT) on stable platforms did not find superior advantages of IRT in strength measures (12). Similarly inconclusive results were previously assessed in adults and adolescents (20) as well leaving open the question whether benefits of IRT over traditional RT on stable platforms exist at all.

Materials and Methods

Understanding of Terms

Using IRT, subjects exercise under metastable rather than unstable states of equilibrium (24). Metastable states of equilibrium may be conceptualized on a continuum between stable and unstable states of equilibrium as endpoints (Figure 1). While machine training may be envisioned as a prototypical example with exercises in stable states of equilibrium lifting loads on a balance beam would be an opposite example for an exercise in a rather unstable state of equilibrium (Figure 2). For exercises in metastable states of equilibrium, subjects continuously aim to maintain balance. In doing so they exert forces based on an interplay of locomotor muscles, stabilizer muscles, through muscle reflex activity, and tendons (24). In this sense, metastability resistance training (MRT) with moderate to large degrees of metastability would be a more appropriate term to denote the above types of exercise rather than IRT. We maintain the MRT term while keeping in mind that in the past literature IRT was used.

Search Strategy and Study Screening

Based on the limited knowledge on the effects of MRT in older adults an updated literature search for original investigations was conducted in the PubMed (1993 to 2020) and Web-of-Knowledge (1993 to 2020) data bases. We used the same Boolean search strategy as Behm and coworkers (3) complemented with keywords addressing older adults above 65 years of age : ("instability resistance training" OR "instability strength training" OR "free-weight training" OR "instability weight-bearing exercise program" OR "instability weight-lifting exercise program") AND (strength OR "muscle strength") AND (elderly OR older OR "elderly adults" OR "older adults" OR seniors OR age"). Only randomized controlled studies were included.

Results

A total of 12 eligible hits were derived following corrections for duplicates and false hits (Figure 3). Studies were excluded when pertaining to unrelated issues like knee surgery, diabetes, cancer, and orthopedics, when addressing mutually excluding balance training or strength training on stable surfaces only, when summarizing original investigations in reviews, or lacking a control group (2, 3). The remaining 12 original investigations were related to RT with either mild or moderate to large degrees of metastability (see Table 1 supplemental material online). In the first case, two studies comparing strength training with free weights to machine-based training in institutionalized older adults (22, 38) were found and one study comparing seated machine vs standing cable training (1). Free-weight training was found to be clinically feasible with a high adherence rate. Similar results in motor tests and functional tests were detected as compared to machine-based training when applied over a period of 12 weeks (22). Increasing the training duration to 26 weeks showed advantages for the free-weight group in limb extension tests (38). Interestingly, free-weight training was found to provide higher values for fun, motivation, future, and benefit for daily life when compared to the machine-based training. No differences were detected when comparing seated machine vs standing cable training (1). From the nine remaining studies four investigations were conducted with Parkinson's disease (PD) patients (37, 40, 41, 42). Interestingly, freely coordinated RT with mild degrees of metastability was found to significantly improve postural control in PD patients using their own body weight or elastic bands to provide resistance (37). However, differences to balance training were only small and not significant. The other three studies conducted by Silva-Batista and coworkers (40-42) related to the same intervention comparing RT and MRT with moderate to large degrees of metastability in patients with moderate to severe states of PD as compared to a control group. While both training protocols improved muscle strength, only MRT improved the mobility, specific motor scores for PD patients, cognitive impairment, and quality of life (40). In addition, larger improvements in muscle activation rates were found in the MRT group despite the lower total training volume as compared to the RT group (41). Moreover, MRT only improved balance performance, overall stability, gait stability, and the fear of falling (42).

The remaining five hits of our literature search related to four training interventions with moderate to large degrees of metastability among healthy older adults (12-14, 19, 37). As one of the first studies on MRT in older adults, Granacher et al. (19) compared the effects of a 9-week MRT for the core muscles as compared to a passive control group. Significant group x time interactions for the isometric strength of trunk muscles in favor of the MRT group were detected. Moreover, training-related improvements were found for spinal mobility, stride velocity, the Functional-Reach-Test, and the Timed-Up-and-Go Test (TUG). In another study, Eckardt (12) compared the effects of two MRT groups (i.e. machine-based with instability devices vs. free-weight on unstable surfaces) with an active control group (machine-based stable RT) on measures of lower-extremity muscle strength, power, and balance in 65 to 80 years old healthy adults over a period of 10 weeks. All groups showed overall similar improvements. However, maximal training load was significantly lower in free-weight MRT compared to machine-based MRT and stable RT. Moreover, machine-based MRT produced the largest improvements in leg extension strength while largest gains in the Chair-Rise-Test and the Functional-Reach-Test were detected for the free-weight MRT.

In a second longitudinal study by Eckardt and Rosenblatt, the effects of a 10-week MRT with free-weights on unstable surfaces were compared to two active control groups (stable machine-based RTs for locomotor muscles or for ›

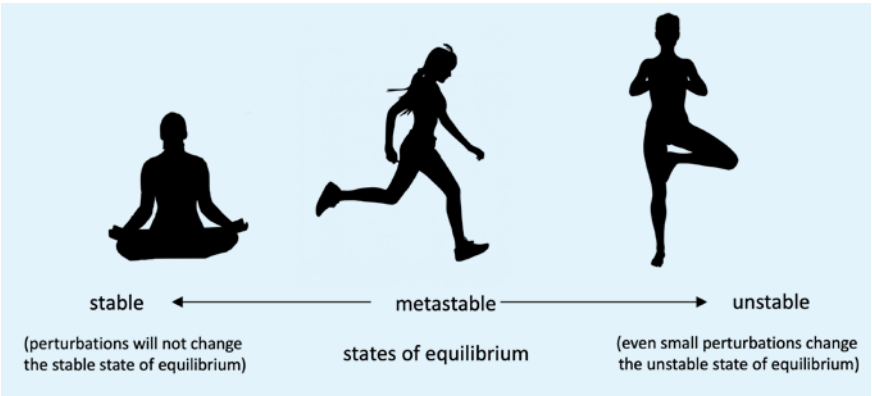

Figure 1

Continuum of human body movements in metastable states of equilibrium between stable and unstable states. Metastability: Property of dynamic systems provided with internal processes to compensate for pertubations and to maintain a metastable state of equilibrium.

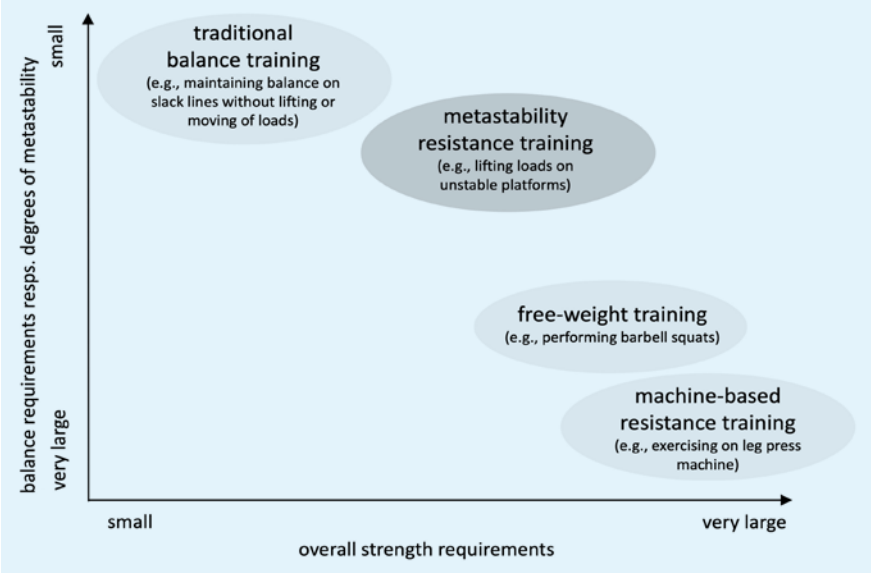

Figure 2

Allocation of training regimes with different balance and overall strength requirements. Only strength training with moderate to large degrees of metastability is considered as metastability strength training.

stabilizer muscles) with a special focus on multijoint coordination during gait (13) and executive functions (14). All groups showed overall similar improvements in strength, balance, and the risk of falls measures. Again, training load was significantly lower in free-weight MRT compared to machine-based RTs. For the leg extension strength, large improvements for the MRT and moderate improvements for RT in the locomotor muscles were found. In contrast, the stabilizer RT did not improve the leg extension strength. Regardless of their group assignment, participants significantly improved their forward reaching whereas backward reaching did not show substantial changes. Noteworthy, a significant time x group interaction for mediolateral proactive balance was found with significant increases in the MRT group only. For the analysis of the multijoint coordination during gait, the mediolateral trajectory of the swing foot was analyzed through an uncontrolled manifold analysis. Interestingly, multijoint coordination was improved on a rippled surface after MRT only resulting in more consistent mediolateral foot placement. In contrast, no group-specific effect of RT on multijoint coordination was detected when walking across an even lab floor. For their focus on executive functions, Eckardt and coworkers (14) found improvements in working memory, processing speed, and response inhibition for the MRT group only with no effects in the stable RT groups.

As a last MRT study with moderate to large degrees of metastability, Pirauá and colleagues (35) compared a 24-week MRT to a traditional RT on stable surfaces and a passive control group on functional mobility, balance, and concern about falling in 64 healthy older adults with an average of 68 years of age. Both MRT and RT groups exercised their core muscles, upper, and lower limbs with moderate intensity loads on unstable versus stable surfaces. There was a significant improvement in balance performance in both intervention groups with larger increases through MRT. Moreover, only MRT resulted in significant improvements for the TUG and the Sit-and-Rise Test with a decrease in the concern about falling.

Discussion

Key Findings

Summarizing the above studies on the specific effects of MRT in older adults several points deserve particular notice. First, MRT appears safe for older adults when properly introduced and supervised. This exercise modality proved to be a feasible alternative for seniors with high adherence rates (12-14, 19, 35) improving muscular strength, power, and balance as compared to controls (3, 19, 35). Second, when compared to traditional RT on stable supports, measures of muscle strength appeared to improve similarly or even larger (11). However, training loads were significantly smaller in MRT than in stable RT (12, 13, 35). As an important consequence, MRT may stress the joints to a smaller degree than traditional RT and its larger loads while producing similar effects. In addition, owing to compensation movements while aiming to maintain a metastable state of equilibrium load may be distributed across larger articular areas. Third, MRT appears to provide an advantage towards RT for measures of functional mobility, balance, and power (35). Unfortunately, in this respect, common tests to assess a risk of falls in older adults are not consistently classified. For example, Eckardt (12) allocated the Chair-Rise-Test as a measure of power in the lower extremities. Significant improvements were found for the two MRT groups as well as for the stable RT group with largest gains through MRT. In contrast, the Chair-Rise-Test was conducted by Pirauá et al. (35) in combination with the TUG to measure functional mobility. Their results demonstrated that MRT provides an enough stimulus to improve both tests compared to the control group. In turn, Eckardt (12) assigned the TUG together with the Functional-Reach-Test to assess proactive balance performance. For the Functional-Reach-Test on a stable surface as well as on a balance pad, MRT groups and the RT group improved their performance with free-weight MRT showing

largest gains. For the TUG an improvement across all groups with a significant main effect of time were found as well. However, no interaction between group x time or any significant post-hoc differences were detected. It is possible that the specific benefits of an MRT in the TUG may depend on the training duration since such differential effect was found in a 24-week intervention (35) but was amiss after the 10-week training period (12). In contrast, Pirauá et al. (35) found improvements in balance performance based on the Berg Balance Scale across both MRT and RT groups with slightly better results for their MRT. Fourth, study results comparing locomotor and stabilizer RT on stable supports with MRT suggest that MRT could be beneficial for the strengthening of stabilizer muscles (13). Assuming that older adults are less exposed to daily activities stressing their leg stabilizer muscles a more pronounced strength decline as compared to locomotor muscles would be expected than in younger adults. This hypothesis was recently supported through a study by Daun and Kibele (7). Here, systematically lower strength values in leg stabilizers muscles as compared to locomotor muscles were found in older females with smaller amounts of daily physical activity. As a consequence, the risk of falls may increase through aging. Further support in this direction comes from studies showing significantly lower leg stabilizer strength in elderly fallers as compared to elderly non-fallers (5, 18, 30, 31). Given, that older adults commonly use exercises for the locomotor muscles in their physical activity programs, MRT may help to strengthen the stabilizer muscles as higher activation levels were detected during metastable as compared to stable exercises. In fact, studies in the literature (for a review see: (23)) detected larger activation rates in the stabilizer muscles when exercising under rather unstable vs. stable conditions. In contrast, smaller or at best similar muscular activation in the primary movers were found for squatting exercises on rather unstable as compared to stable platforms. In turn, larger activation rates are found in the locomotor muscles as compared to stabilizers when exercising under stable conditions. Consequently, indirect evidence suggests that MRT with moderate to large degrees of metastability could provide a better training stimulus for the stabilizer muscles than for the primary movers (33). However, more specific training studies are needed to support this hypothesis.

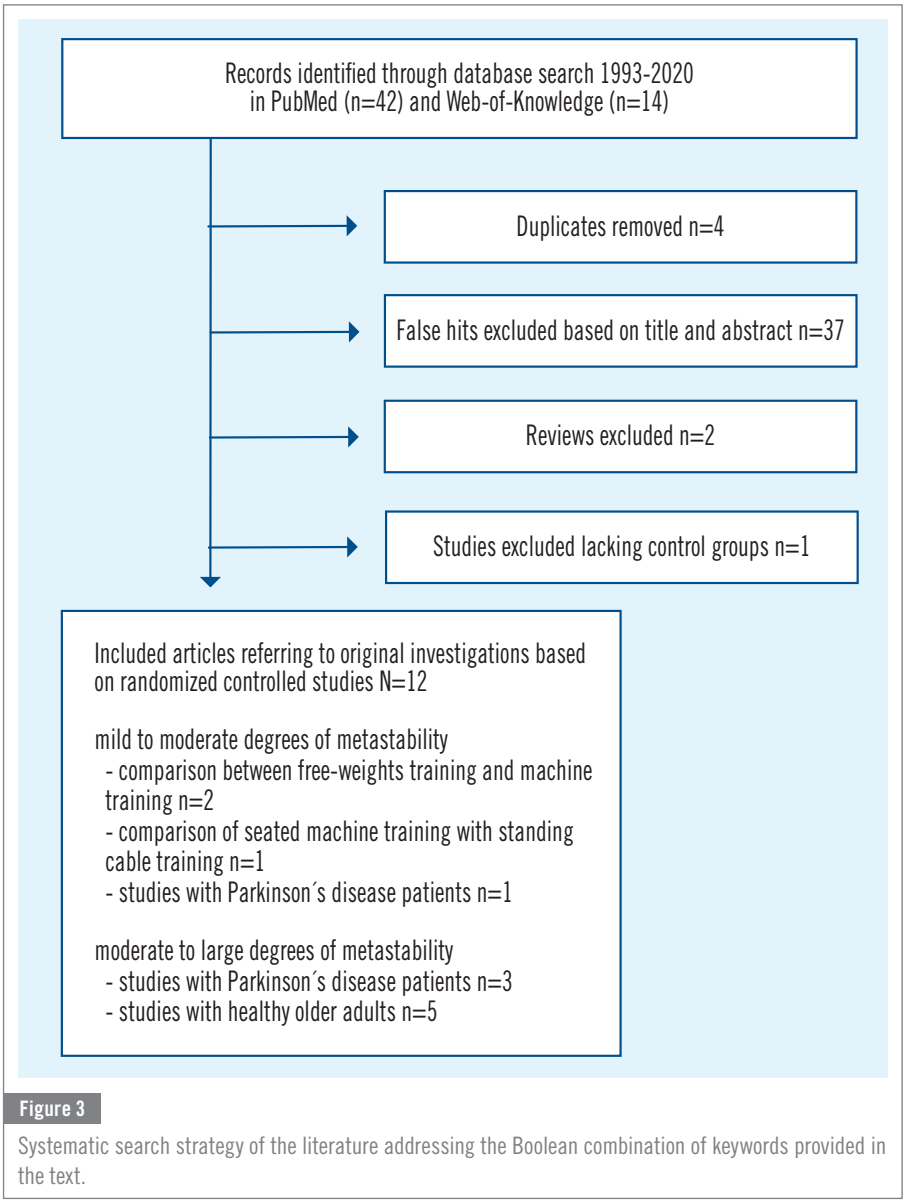

Figure 3

Systematic search strategy of the literature addressing the Boolean combination of keywords provided in the text.

As a fifth point, MRT has the potential to stabilize gait when being challenged, e.g. on rippled surfaces (13), and, thus, may reduce the risk of falls in older subjects. Noteworthy, mediolateral gait stability was previously identified as a main predictor of falls in older adults (4, 36). The above reported improvement in the multijoint coordination during gait on rippled surfaces (13) could be part of a unique control strategy when exercising on metastable surfaces as previously observed in athletes (46) and now employed by older adults through MRT to reduce the risk of falls (13). As a last and most surprising effect, MRT may not only improve the physical performance of older adults but cognition as well. In this respect, reductions in the fear of falling (FOF), particularly through extended training periods (35), and increases in the executive functions (EF) (14) have been reported. While FOF is closely related to poor health outcomes in older adults (45) interventions to reduce it are mandatory for older adults (26). The beneficial effect of MRT in older adults receives further support by Paraschiv-Ionescu et al. (34) concluding that older adults capable of performing more complex tasks show smaller degrees of FOF. Significant reductions in the FOF have been demonstrated in MRT interventions after 10 weeks (12, 13) as well as 24 weeks (35), and even in PD patients of older age (40). In addition to reductions in the FOF, MRT may have the potential to improve EF in older adults as well. Core EFs refer to response inhibition (self-control: resisting temptations and impulsive actions; interference control: selective attention and cognitive inhibition), working memory, and cognitive flexibility (e.g., creative thinking, adopting different perspectives, or responding quickly and flexibly to changing circumstances) (8).

There is an ongoing debate whether RT in general may provide an enough stimulus to improve EF (10, 28, 29, 43). While improvements have been observed in older adults following RT (16, 29) other authors have questioned a general effect ›

independent of the specific RT application (10, 43). On one side, researchers supporting a positive effect of RT on EF have argued that increases in insulin like growth factor as well as decreases in serum homocysteine following RT may improve EFs (28, 29). On the other side, researchers have questioned whether general effects of aerobic exercise or RT exist at all for cognitively less demanding activities (10). Instead, activities promoting attention, reduction of stress, and loneliness are thought to produce improvements in EF in older adults (10). For this debate, the study of Eckardt et al. (14) offers a new perspective combining both alternatives. Their MRT group improved working memory, processing speed, and response inhibition while no improvements in EFs were found for stable RT. The reasons for this differential effect could relate to the specific cognitive demands when exercising on, or with, unstable devices and learning new movements (44). During MRT, subjects are in a state of constant alert while incessantly forced to monitor their state of equilibrium and counteract perturbations. Therefore, aside from physical capacities, neurotrophic factors, and metabolic responses, attentional resources may be responsible when improving EFs as hypothesized by Diamond and Ling (9). In addition, counteracting imbalance disruptions is particularly challenging for older adults who may not believe of being capable to meet such age-atypical demands owing to an age-stereotype threat (21, 27). This effect is found in older adults facing pervasive negative stereotypes that memory, cognitive, and physical competence decline with age. Therefore, it appears likely that the imbalance disruption imposed by unstable surfaces may not only improve balance and muscle strength. It might, as well, improve EF in older adults through increased confidence to perform daily tasks of greater complexity, novelty, and variety (32).

Last not least, indirect evidence suggests that while EF improve through increases in dopaminergic activity (15) which, in turn, result from positive feedback in exploratory behavior (11) such as lifting loads on unstable platforms, these EF improvements could relate to MRT or else originate from traditional RT (25). Overall, MRT could have a distinct potential to improve EF based on motivational, cognitive, hormonal, or neurotrophic changes.

Conclusion

Based on the above review, MRT may be beneficial for the older adult for several reasons including motor and cognitive effects when properly introduced and supervised. So, instead of avoiding instability completely, older adults may utilize it carefully to prevent for falls and to maintain a healthy lifestyle. As a limitation of this review, more studies are needed to further support this conclusion.

Conflict of Interest
The authors have no conflict of interest.

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