Influence of the Value of Effort on the effectivenes of HIIT on the physical and cognitive abilities of older adults

Bachelorarbeit

Zur Erlangung des akademischen Grades

Bachelor of Science (B.Sc.)

vorgelegt von

Jonathan Wientges

01/997375

Mathematisch-Naturwissenschaftliche Sektion

Fachbereich Psychologie

Arbeitsgruppe Sportpsychologie

Gutachter: Herr Dr. Maik Bieleke

Konstanz, Januar 2024

Abstract

As global societies experience continuous aging of the population, the strain of age-related physical and cognitive impairments on healthcare systems intensifies. Traditional interventions aimed at promoting physical fitness and preventing cognitive decline have demonstrated only limited and short-term effectiveness. This pilot study investigates the impact of the Value of Physical Effort (VoPE) on the effectiveness of a Jump High-Intensity Interval Training (Jump HIIT) intervention in enhancing physical and cognitive fitness among elderly individuals. Guided by the Theory of Learned Industriousness, I hypothesize that an increase in the VoPE, cultivated through participation in the intervention, will positively influence the effectiveness of Jump HIIT in improving physical and cognitive performance. Seventeen participants underwent extensive baseline and follow-up measurements, assessing various cognitive and physical performance parameters and engaged in a 10-12 week Jump HIIT intervention. A Bayesian analytical approach provides evidence supporting an increase in the VoPE and subsequently a positive influence on maximum jump height in the countermovement jump. However, mixed and inconclusive findings were observed for other physical and cognitive performance parameters. These preliminary findings suggest a potential benefit of increased VoPE, positively influencing the effectiveness of a Jump HIIT intervention. Nonetheless, robust conclusions require replication through a randomized controlled trial. Further research in the area of effort value should focus not only on exploring the mechanism of its formation but also on investigating the complex relationships with human behaviour, as piloted in this work.

Keywords: Value of Physical Effort, Jump High-Intensity Interval Training, Countermovement Jump, Elderly Individuals

Zusammenfassung

Im Zuge der weltweiten Alterung sehen sich Gesellschaften zunehmend mit der Herausforderung konfrontiert, die durch altersbedingte körperliche und kognitive Beeinträchtigungen auf die Gesundheitssysteme zukommt. Bisherige Interventionen zur Förderung körperlicher Fitness und zum Schutz vor kognitivem Abbau zeigen lediglich begrenzte und kurzfristige positive Effekte. Diese Pilotstudie untersucht die Rolle des Werts der Anstrengung auf die Effektivität einer Sprung Hoch-Intensitäts-Intervall Trainings (Sprung HIIT) Intervention zur Förderung körperlicher und kognitiver Leistungsfähigkeit bei Senior:innen. Basierend auf der Theorie des erlernten Fleißes wird die Hypothese aufgestellt, dass eine Steigerung des Werts der Anstrengung, die durch die Teilnahme an der Intervention erreicht wird, einen positiven moderierenden Einfluss auf die Effektivität der Sprung HIIT-Intervention zur Steigerung der körperlichen und kognitiven Leistungsfähigkeit haben wird. Siebzehn Teilnehmer:innen nahmen an umfangreichen Prä- und Postmessungen zahlreicher kognitiver und physischer Leistungsparameter sowie an einer 10- bis 12-wöchigen Sprung HIIT-Intervention teil. Ein bayesianischer Ansatz zur Überprüfung der Hypothesen liefert Hinweise auf eine Steigerung des Werts der Anstrengung und einen positiven Einfluss dieser Steigerung auf die maximale Sprunghöhe im Gegenbewegungssprung. Gemischte Befunde wurden für andere physische und kognitive Leistungsparameter gefunden. Diese vorläufigen Ergebnisse deuten darauf hin, dass eine Steigerung des Werts der Anstrengung potenzielle Vorteile bietet und einen positiven Einfluss auf die Effektivität einer Sprung HIIT-Intervention haben könnte. Dennoch sind belastbare Schlussfolgerungen erst nach einer Replikation in einer randomisierten kontrollierten Studie möglich. Weitere Forschung in dem Gebiet des Wertes der Anstrengung sollte nicht nur den Entstehungsmechanismus weiter erforschen, sondern auch, wie in dieser Arbeit pilotiert, die komplexen Beziehungen zum menschlichen Verhalten untersuchen.

Schlüsselwörter: Wert der physischen Anstrengung, Sprung Hoch-Intensitäts Intervall Training, Gegenbewegungssprünge, Senior:innen

Contents

List of Figures

List of Tables

Introduction

The demographic landscape is undergoing a significant shift, marked by a discernible trend towards an aging population. According to projections from the Directorate General for Economic and Financial Affairs (2021), the anticipated population in the year 2070 demonstrates a noteworthy decrease in age cohorts spanning from 0 to 64 years, while conversely, the population aged 65 years and older will increase considerably. This demographic shift, marked by a growing elderly population, is placing a strain on healthcare systems worldwide as the current healthcare infrastructure faces challenges in managing older patients with multiple comorbidities and functional impairments (M.-H. Lin et al., 2010; Pammolli et al., 2012). With numerous diseases and impairments contributing to the issue and limiting the well-being and life expectancy of the aging population, it is imperative to address the specific challenges. I will focus on three important areas that can serve as indicators of well-being and health.

Impacts of Aging: Sarcopenia, Cardiorespiratory Fitness, and Cognitive Impairment

The term sarcopenia, signifying "loss of flesh," was introduced in 1988 to characterize the age-associated decline in skeletal muscle mass (Rosenberg, 1997). Beyond the mere reduction in muscle mass, functional changes associated with sarcopenia contribute significantly to an increase in weakness, fractures, and an elevated tendency for nursing home admissions, ultimately leading to a loss of independence (Rosenberg, 1997). Notably, a 30% decrease in whole muscle size transpires between the ages of 50 and 80 years (Deschenes, 2004), coupled with an annual strength loss ranging from 1.5% to 5% in individuals older than 50 years (Marcell et al., 2014). Lower limb strength loss can lead to diminished functionality and mobility, resulting in increased risks of falls among older individuals (Buchman et al., 2007; Meyer et al., 2012). Furthermore, sarcopenia is associated with a spectrum of adverse outcomes, extending even to older individuals without overt disease, including disability, hospitalization, and mortality (Guralnik et al., 2000; Verghese et al., 2006). The decline in muscle strength can lead to an inability to perform activities of daily living, such as household chores and self-care, contributing to a loss of functional independence among the aging population (Janssen et al., 2002; Reid et al., 2008).

Cardiorespiratory fitness, as measured by the maximum amount of oxygen ones body can absorb and use during exercise (VO2max), declines substantially with age. The rate of decline increases from 3% to 6% per decade in one's 20s and 30s to exceeding 20% per decade in one's 70s and beyond (Fleg et al., 2005). The rapid decrease in aerobic capacity represents a substantial challenge, as cardiorespiratory fitness is closely linked to various health outcomes. It serves as a significant mortality predictor in older adults, independent

of overall or abdominal adiposity (Sui et al., 2007). Additionally, cardiorespiratory fitness is an independent predictor of mortality and length of hospital stay in patients after a liver surgery, providing more accurate prognostic information than age alone (Snowden et al., 2013). Cardiorespiratory fitness is even theorized to regulate telomere length in middle-aged and older adults, thereby potentially moderating the cellular aging process (Marques et al., 2020). Therefore, the significant decline in cardiorespiratory fitness with age, as measured by VO2max, is a crucial factor in health outcomes, mortality prediction in older adults, and prognostication in post-liver surgery patients. Additionally, its theoretical connection to moderating the cellular aging process makes cardiorespiratory fitness an excellent indicator of physical abilities within the target population.

In the context of research involving elderly populations, the term "Cognitive Impairment" is frequently employed to denote a spectrum of cognitive deficits associated with aging. From the age of 71 and beyond, there is a notably high prevalence of cognitive impairment among the elderly population, with an estimated 5.4 million people (22.2%) in the United States aged 71 years or older exhibiting cognitive impairment without dementia (Plassman et al., 2008). Furthermore, cognitive impairment is recognized as a significant risk factor for the development of dementia (Comas-Herrera et al., 2007). The implications of cognitive impairment extend beyond individual well-being, impacting healthcare systems economically. Baumgart et al. (2015) predict that expenditure on long-term care services for older individuals with cognitive impairment in the UK will increase from £5.4 billion in 2002 to £16.7 billion in 2031. However, researchers emphasize the importance of physical activity as a potential protective factor against cognitive impairment. Physical activity interventions are believed to have a beneficial impact on cognitive abilities, potentially slowing cognitive decline directly through increased blood flow or indirectly by reducing other risk factors, such as cardiovascular disease, obesity, and diabetes (Brasure et al., 2018).

Reassessing Aging Interventions

Numerous health-related training interventions have been implemented to attempt to protect the elderly population from the aforementioned cognitive and physical decline associated with aging. Despite sustained efforts, existing reviews have yet to establish compelling and enduring effects of interventions on both cognitive and physical fitness. A comprehensive review of physical activity interventions, including home-based, group-based and educational approaches, indicates that while these interventions can lead to increased physical activity, the changes observed tend to be modest and short-lived (van der Bij et al., 2002). In a recent umbrella review assessing the effectiveness of interventions aiming to increase physical activity and/or reduce sedentary behaviour among community-dwelling older adults, Alessy et al. (2023) found some evidence supporting short-term effectiveness

of these intervention ($\leq$ 3 months). However, the review also highlights a notable gap in high-quality evidence concerning the long-term effects of these interventions. Furthermore, a systematic review conducted by Brasure et al. (2018) specifically focusing on physical interventions for cognitive impairment found that evidence supporting the effectiveness of single-component physical activity interventions in preventing cognitive decline is largely insufficient.

In light of the persistent challenges in mitigating cognitive and physical decline among the elderly through existing health-related training interventions, a critical reassessment of the variables influencing human health behaviour is imperative. Despite numerous attempts, comprehensive reviews have thus far failed to yield conclusive evidence supporting the sustained efficacy of interventions targeting cognitive and physical fitness in aging individuals. To fill this critical gap in our understanding, it is essential to explore the complex web of factors that shape health outcomes in the older population. Among the potentially influential factors, one aspect that has been notably absent from previous investigations is the *Value of Effort*.

Decoding Effort in Sports

The emphasis on effort is crucial in the context of sport and physical activity due to its defining nature within these domains. The Cambridge-Dictionary (n.d.) defines Sport as "A game, competition, or activity needing physical *effort* and skill that is played or done according to rules, for enjoyment and/or as a job". Furthermore, Wolff et al. (2021) stated that exercise induces the sensation of effort, a subjective experience that involves the investment of physical and mental energy. Effort itself, in turn, can be defined as the subjective intensification of mental and/or physical activity in the service of meeting some goal (Eisenberger, 1992). It is essential to distinguish effort from motivation. Effort refers to the intensity or amplitude of behavior but does not inherently specify a particular goal. In contrast, motivation is a driving force that not only determines the intensity or vigor of behavior but also provides a direction, such as a specific goal (Atkinson, 1957; Pessiglione et al., 2018). While effort is the exertion applied to an activity, motivation adds the crucial element of purpose and direction to that exertion. Effort is accompanied by distinct phenomenology, making it evident to the actor that they are exerting effort (Kurzban, 2016) and recognizable to others whether somebody is exerting effort or faking it (de Morree & Marcora, 2010; Grèzes et al., 2004; Tidoni et al., 2013; A. van Boxtel & Jessurun, 1993). Exertion of Effort is often considered aversive (Kurzban, 2016) and is avoided if possible (Brehm & Self, 1989). In his Principle of Least Effort, Zipf (1949) describes that people will choose to minimize their effort to achieve their goals, thus indirectly proposing that effort is always both costly and instrumental to reaching a set goal (Brehm & Self, 1989).

Instrumental Effort

The historical perspective, prevalent in literature to date, regards effort as a tool for achieving goals, wherein individuals endure and persevere through it. Contemporary theoretical and empirical work in cognitive neuroscience and economics, as highlighted by Inzlicht et al. (2018), has predominantly supported this historical view. The consensus emerging from recent research is that effort is inherently costly and devalued. In the context of effort's utility, the Motivational Intensity Theory (MIT) conceptualizes effort as a strategic tool that is always seen as a cost, and individuals decide to apply effort based on a careful weighing of potential benefits against the amount of effort required (Brehm et al., 1983), only applying effort as an instrument to the degree justified by a potential reward. MIT has proven to be a useful framework in understanding how people allocate physical effort, particularly as a costly but instrumental means of goal pursuit (Richter et al., 2016) and is well-documented, especially in the cognitive domain (Frederick, 2005; Kool et al., 2010; Westbrook et al., 2013). People exhibit a dislike for even the smallest amounts of effort, such as the mental effort required for thorough thinking about an option (Kool et al., 2010). This avoidance of effort extends to both humans and other animals (Frederick, 2005; Kool et al., 2010). When faced with tasks offering equal rewards but differing in levels of demand, organisms, including rats navigating mazes, demonstrate a learning pattern to avoid the more demanding option. Just as rats typically learn to avoid the physically demanding arm of a maze (Hull, 1943), research by Cocker et al. (2012) suggests that organisms also learn to avoid more cognitively demanding choice options. Humans showcase the perceived costliness of effort through a willingness to accept fewer rewards if it helps them avoid higher effort (Westbrook et al., 2013). There is neuroscientific evidence for the subjective aversiveness of effort. Activity in both the anterior cingulate and the anterior insula have been shown to correspond to effort discounting (Arulpragasam et al., 2018; Massar et al., 2015) and to potentially mediate the subjective aversiveness of effort (Botvinick & Rosen, 2009).

Rethinking Effort: Towards the Value of Effort

However, this notion that effort is inherently costly and instrumental, only applied if potential benefits outweigh the costs, has recently been challenged both in the cognitive (Inzlicht et al., 2018) and physical (Stähler et al., 2023) domain. Most importantly, the available evidence supports the idea that effort can have inherent value (Inzlicht et al., 2018; Stähler et al., 2023). To gain further insight into the shifted perception of effort, two paradoxical examples can be utilized, which are inexplicable by means of the traditional concept of effort. Firstly, recreational endurance athletes commit significant resources, including time, money, and the potential risk of injury, to participate in demanding endurance

events despite limited chances of receiving tangible rewards in return (Maxcy et al., 2019). Secondly, individuals demonstrate a preference for climbing activities due to the inherent effort required. The answers to the question commonly asked of mountaineers about their motivation for climbing mountains are often unclear because these reasons do not fit neatly within the described instrumental functions of effort (Loewenstein, 1999). Derived from these and other examples, Inzlicht et al. (2018) propose three functions of effort, namely *effort as instrument*, *effort as reward* and *effort as value added*. Stähler et al. (2023) find support for this distinction into three functions in the physical domain literature. Besides the aforementioned effort as a costly instrument, the effort as reward describes that the activity is valued because it requires a substantial amount of effort. The outcome, or potential reward is not a driver for the behavior but rather the sheer experience of effort (Stähler et al., 2023). This function is also known as the Value of Physical Effort (Bieleke et al., 2023). Additionally, Inzlicht et al. (2018) highlight the Effort as Value Added. People often assign more value to the same outcome or reward when they had to exert more effort to obtain it. This effect is sometimes referred to as the "Ikea Effect". For an extensive review, please see Stähler et al. (2023).

In the following paragraph I would like to give a brief insight into the supporting literature of the value of physical effort described above. In a series of studies conducted by Stanek and Richter (2021), participants applied greater effort in an isometric hand grip task than was necessary to complete the task and receive the reward. This finding can be interpreted as indirect evidence for the value of physical effort, as it cannot be accounted for by purely instrumental approaches to effort. In their survey, Wright et al. (2005) examined the relationship between exercise self-efficacy and motivational responses to physical activity. Results revealed that individuals who exhibit higher levels of comfort with exercise tend to find greater enjoyment in it and perceive physical exertion as rewarding. There is consistent evidence for a value adding function of physical effort (Palidis & Gribble, 2020; Turner et al., 2021; Vinckier et al., 2019).

Mechanism of Emergence: The Learned Industriousness Theory

But why do people value effort? One of the leading theories of emergence for this phenomenon is a reinforcement learning mechanism (Haynos et al., 2023; Inzlicht et al., 2018; Stähler et al., 2023). There is a substantial body of learning research spanning several decades, which demonstrated that rewards play a pivotal role in positively influencing preferences for more challenging tasks and increased effort exertion in both humans and non-human subjects (Crespi, 1942; Leonard et al., 2017; O'Doherty et al., 2017). It is noteworthy that incentivising task performance can lead to reduced intrinsic value and willingness to exert effort, especially after the reward is withdrawn (Henderlong Corpus &

Lepper, 2007; Mueller & Dweck, 1998). But when individuals are rewarded for engaging in more demanding tasks, even without controlling for the distinction between performance and actual effort, there is an evident heightened willingness to exert effort in subsequent tasks. A positive effect of reward on maintenance of effort exertion was demonstrated by Eisenberger et al. (1979), who found that rats trained to exert high effort for reward showed increased effort in subsequent tasks and a preference for high-effort activities. Similarly, rewarding high-effort expenditure on difficult tasks enhanced effort and persistence on subsequent unrewarded tasks in humans, while also reducing cheating on challenging math assignments (Eisenberger & Masterson, 1983; Eisenberger et al., 1979). This positive impact of rewards on sustained effort aligns with the concept of *Learned Industriousness* proposed by (Eisenberger, 1992), where conditioning of high effort as a secondary reinforcer, when consistently paired with primary rewards like money, social praise or mastery experience can lead to an inherent rewarding value of effort itself. This mechanism has been previously studied for its role in valuing physical effort. Studies have shown that both human and non-human subjects demonstrate a greater willingness to exert physical effort, and therefore value physical effort, in subsequent non-rewarded tasks following a repeated coupling of high effort and rewards (Bernacer et al., 2019; Laurence et al., 2015). More recently, it has been hypothesized that the Learned Industriousness mechanism is a major contributor to the clinically relevant overvaluation of effort in anorexia nervosa patients (Haynos et al., 2023).

The Generalization of Effort Valuation

The Value of Effort has been proven not to be task specific, but rather to generalize across a variety of tasks with different demands within a domain. This holds true for both the cognitive and physical domains. H. Lin et al. (2021) exemplify this by demonstrating that rewarding participants for choosing a challenging inhibition task during training increases their willingness to perform another cognitively demanding task without reward, suggesting a domain-specific but task-unspecific generalization phenomenon. Additionally, the results from studies conducted by Eisenberger and Adornetto (1986) and Eisenberger and Leonard (1980) offer further backing for the generalization of effort valuation. College students and preadolescent children who receive rewards for successfully completing challenging cognitive tasks tend to demonstrate a greater willingness to exert more effort and to engage more persistently in unrelated tasks without being rewarded. Correspondingly, analogous effects have been elucidated in the context of Learned Industriousness within the physical domain. Experiments with rats, revealed that following the repeated association of high effort with reward in one specific physical task, rodents exhibit an amplified willingness to exert increased effort in a distinct, unrelated physical task (Eisenberger et al., 1979).

An ongoing debate in the scientific community considers whether the Value of Effort is domain-specific or general across different domains. This query aims to distinguish whether an increase in value of physical effort, for example, simultaneously affects the valuation of cognitive effort, and vice versa. Theories of effort regulation highlight the interrelated nature of cognitive and physical effort regulation (Herrebrøden et al., 2023; Wolff et al., 2021). In sports performance, physical and cognitive effort are often intertwined. Performance in an endurance race relies on physical effort, such as the engagement of locomotor muscles, but at the same time self-regulatory control, which is required to override automatic response tendencies, such as stopping or slowing down (Wolff et al., 2021). Contrary to dualistic views that attempt to separate mind and body, it's crucial to recognize their inseparability in the context of sport. Increasing or maintaining physical effort inherently involves cognitive effort, emphasizing the interrelated nature of these two facets (Herrebrøden et al., 2023). Neurological evidence supports the notion of a shared neurological evaluation of effort across cognitive and physical domains (Chong et al., 2017; Ritz et al., 2020). The exploration of cross-domain evaluation of effort has yielded varied results regarding the existence of a common value of effort (Bustamante et al., 2014; Chong et al., 2018; Jonker et al., 2010). A survey comparing elite athletes and non-athletes revealed a positive correlation between willingness to exert physical effort and academic performance. Elite youth athletes achieved higher levels of education than their non-athlete peers, and an increased willingness to exert effort was associated with not only superior athletic performance but also academic achievement (Jonker et al., 2010). Another comparison between athletes and non-athletes revealed distinct patterns in physical and cognitive effort avoidance within each group. While athletes showed no variance between domains, non-athletes differed between the physical & cognitive domain (Chong et al., 2018). This indicates that there is no consistent, cross-domain value of effort. One study examined the transferability of effort valuing across different domains using a reinforcement learning paradigm. In a between subject's design, participants were either rewarded for high or low physical or cognitive effort and their persistence on a subsequent non-rewarded cognitive task was measured. There was no evidence that learned industriousness generalized across domains (Bustamante et al., 2014). Stähler et al. (2023) suggest that the complexity of the relationship between effort costs across domains (as described in Chong et al., 2018) may help to explain the failure to generalize effort valuation across domains in Bustamante et al.'s 2014 study, as the association between reward and high effort only occurred during a short (10 min at most) training period.

The Interplay Between Value of Effort and Cognitive & Physical Abilities

The inquiry into the correlation between Value of Effort and cognitive or physical ability prompts an exploration into the underlying factors that link heightened effort values with potential benefits for the elderly, acting as a protective mechanism against age-related health risks. The question revolves around the degree to which increased valuing of effort correlates with advantageous effects on the capabilities of the elderly. This assumption hinges on the premise that a positive association between valuing effort and cognitive or physical ability could contribute to enhancing overall well-being and resilience in the face of challenges associated with aging. The value of physical effort, in contrast to its cognitive counterpart, has received limited research attention (Stähler et al., 2023). In stark contrast, the value of cognitive effort, often referred to as the *Need for Cognition* (NFC), has been a subject of prolonged and established research recognition. The NFC represents an individual's inclination to engage in and derive enjoyment from cognitively demanding activities and is a widely acknowledged personality trait (Cacioppo et al., 1996). Therefore, I will focus on NFC to illustrate how a higher value of effort can help older people's abilities and argue that the value of physical effort should have similar effects because of their close similarity. Individuals with a higher NFC generally favor engaging in leisure activities that require more cognitive effort (Therriault et al., 2015), show lesser effort devaluation in an effort discounting paradigm (Westbrook et al., 2013) and require less incentives to engage in cognitive effortful tasks (Sandra & Otto, 2018), particularly when contrasted with those with lower NFC levels. A cross-sectional study, based on a representative sample of elderly individuals from the US population (N=1,174), has reported a strong positive association between NFC and neurocognitive ability (Maldonato et al., 2017). Longitudinal Designs investigating the impact of NFC on cognitive ability changes discovered and replicated that (a) higher initial NFC predicted greater cognitive abilities two years later (Baer et al., 2013), and (b) a positive change in NFC was linked to positive changes in cognitive abilities (Hess et al., 2012). On the basis of the literature, the researchers believe that they have found sufficient evidence to support the hypothesis that higher (changes in) value of cognitive effort leads to greater cognitive ability and may therefore help to protect against cognitive impairment (Baer et al., 2013). In conjunction with the relatively scarce exploration of the value of physical effort, a domain that has exhibited parallels with research findings on cognitive effort, an assumption can be made regarding the positive correlation between the value of physical effort and physical fitness in old age. Drawing on the existing body of research that has consistently revealed a positive correlation between the value of cognitive effort and cognitive abilities in the elderly, the analogous nature of the research on the value of physical effort, as characterized by similiar devaluation patterns (Białaszek et al., 2017; Lopez-Gamundi & Wardle, 2018) suggests a potential parallel in the physical domain.

The Jump High Intensity Interval Training

A High-Intensity Interval Training (HIIT) was implemented as an efficacious training intervention for elderly individuals. Numerous reviews provide robust evidence supporting the efficacy of HIIT for enhancing cardiorespiratory fitness (Costigan et al., 2015; Kilpatrick et al., 2014) as well as some evidence suggesting moderate effects of HIIT on executive function (Costigan et al., 2016). Additionally, HIIT that includes various forms of jumps and lunges has proven to be a practical technique in curtailing muscle atrophy (Kramer et al., 2018). As a result, Kramer et al. (2018) suggest for sedentary populations to incorporate this routine as a preventive measure. Still, to the best of my knowledge, no previous study has implemented a Jump High-Intensity Interval Training (Jump HIIT) intervention incorporating among others lunges and jumps specifically tailored for the at-risk population of the elderly. Physiological markers of exertion in Jump HIIT have been identified to exhibit a high correlation with well-researched types of HIIT, such as running and cycling (Kramer et al., 2019). Moreover, these physiological markers are strongly associated with the subjective exertion reported by individuals in self-reports, such as the Rating of Perceived Exertion (Borg, 1982; Robertson & Noble, 1997).

It is difficult to find extensive literature regarding the different rewards, that people experience within sporting participation. For the most part, the motivation for sport is researched. Nonetheless, there is some evidence that people value both, the opportunity for social interaction during sport, as well as the hedonic pleasure they experience. Findings from an interview-style study conducted within US community sport and leisure-time physical activities revealed that participants emphasized the significance of hedonic rewards, referring to the positive feelings experienced after training, and social interaction during sporting participation (Berg et al., 2015). I anticipate that participants derived hedonic rewards and benefits from social interactions during the exercises, facilitated by their encouragement to train in small groups. The incorporation of challenging training sessions theoretically should have yielded a sense of personal satisfaction. Beyond these intrinsic rewards, it is plausible to assume that participants may have also received social praise from their peers for their active involvement in a physical activity training program.

Based on the literature, I conclude that the Jump HIIT Intervention should not only be an effective way to improve both the cardiorespiratory fitness and strength in the lower extremities but also should be experienced as highly effortful and offers opportunities for indirect rewards.

Purpose of the Study

This study seeks to explore the role of the Value of Physical Effort in the context of health-related interventions for the aging population. Through investigation of this often-

unrecognised variable, I aim to refine the understanding of the complexities surrounding health behaviours in older people, with the ultimate goal of tailoring interventions that are not only specific, but also inherently effective in promoting sustained cognitive and physical well-being in the future.

This theoretical base leads me to the following research question: How does a change in the subjective value of physical effort in the context of Jump HIIT relate with the physical and cognitive fitness of elderly individuals? If one considers that the Jump HIIT Intervention should be experienced as both effortful and rewarding (social praise, personal satisfaction & social interaction) one can assume that through a reinforcement learning mechanism called Learned Industriousness (Eisenberger, 1992), participants will learn to value the physical effort exerted more. I therefore postulate that after the repeated exertion of high effort in the Jump HIIT and coupling with social and self-fulfilling rewards, the value of physical effort will increase.

I also anticipate a greater positive change in the value of physical effort to positively correlate with an improvement in physical fitness. Although, there is no direct evidence in the literature (since the concept of value of physical effort is brand new) this makes sense from a theoretical standpoint. As I laid down, a positive change in the value of cognitive effort leads to greater positive changes in cognitive abilities (in longitudinal designs; Hess et al., 2012) and a higher value of cognitive effort is overall positively correlated with greater cognitive abilities in elderly populations (Baer et al., 2013). Thanks to the great similarities regarding the effects between the well – researched value of cognitive effort and the newer concept of value of physical effort in the literature, I propose that similar patterns can be found in the physical effort domain. This also makes sense if one considers that people with a higher value of cognitive effort seem to seek out effortful leisure time activities (Therriault et al., 2015) and require less incentives to exert higher levels of effort (Sandra & Otto, 2018). Both characteristics, if translated to the physical domain, would increase the physical fitness of an individual.

Lastly, I postulate a greater positive change in the value of physical effort to positively correlate with an improvement in the cognitive fitness as well. Research has shown mixed results so far regarding the across domain generalization of the Value of Effort. While theories of the regulation of effort (Herrebrøden et al., 2023; Wolff et al., 2021) and neuroimaging studies (Chong et al., 2017; Ritz et al., 2020) hint towards a common learning mechanism for both, the cognitive and physical valuation of effort, experimental (Bustamante et al., 2014; Chong et al., 2018) and questionnaire studies (Jonker et al., 2010) have failed to show consistent results. I therefore want to test this generalization based on the theoretical construct explained earlier.

Methods

Participants

The study involved a total of N = 17 healthy subjects who voluntarily participated in the research. Five subjects (two men and three women) withdrew from the study, citing reasons unrelated to the project, and were unable to complete the measurments. Ultimately, data from N = 12 participants were obtained, comprising n = 7 females (mean age 63.57 ± 2.88 years) and n = 5 males (mean age of 73.00 ± 4.30 years). The age range of the participants spanned from 60 to 78 years. All participants were affiliated with the Litzelstetten tennis club. Inclusion criteria included being German speakers, having no injuries in the previous six months, having no heart problems, and being active tennis players. The study adhered to ethical principles and received approval from the Ethics Committee of the University of Konstanz with confirmation number 29/2022. The study design was in accordance with the Declaration of Helsinki. Prior to participation, all participants were informed about the study, provided their consent and confirmed that they did not suffer from any medical conditions that could influence the results or compromise their health in any aspect.

Study Design

The research adopted a longitudinal pilot study design, incorporating baseline and follow-up measurements. All physiological and psychological performance tests, along with the questionnaires (with the exception of the prospective and retrospective formulations of the RoE scale), remained consistent in both measurement phases. The study involved participants in a 10-12-week Jump High-Intensity Interval Training (Jump HIIT) program.

During the intervention phase, participants adhered to a structured training regimen, involving three sessions per week, each lasting 20 minutes, with a rest day between sessions. The training program comprised eight different exercises (e.g., Counter Movement Jumps, Skipping, Running on a Spot, Quick Squats), with five to be completed in a session. A detailed description of the exercises can be found in Appendix A. Despite variations in exercises throughout the sessions, the load of 20 seconds per exercise with a 40-second break between exercises remained constant.

The exercises and training plan were thoroughly discussed with the participants. A member of the Chair of Training and Movement Science at the Human Performance Research Centre (HPRC) of the University of Konstanz provided explanations on the correct execution of the exercises during the first meeting. Participants performed all further sessions independently, either at home or outside and were encouraged to carry out the exercises in small groups. Each participant received a printed training plan outlining the

exercises for each session, including space to record the duration of each training session (see Appendix B).

Materials

Value of Effort

So far, little attention has been paid to the Value of Effort in the physical domain (Stähler et al., 2023), but recent advancements, such as the introduction of the Value of Physical Effort (VoPE) scale (Bieleke et al., 2023), have allowed researchers to delve into this aspect. By employing the VoPE scale, researchers demonstrated that individuals differed in their valuation of physical effort, and these individual differences were correlated with various aspects of sports behavior, exercise volume, and overall physical activity outcomes (Bieleke et al., 2023). The scale contains items such as "I prefer physically effortful sports activities to those that can be done without much effort". Participants expressed their agreement with each item on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). Subsequently, their individual responses were averaged to derive an overall Value of Physical Effort (VoPE) score. The complete Value of Physical Effort (VoPE) scale is presented in Table 1.

A longitudinal study showed a moderate correlation over time, suggesting that the VoPE scale captured changes in the value of physical effort (Bieleke et al., 2023). As a supplement to the trait measure of effort, I used an as yet unpublished scale in this study, which, due to its prospective and retrospective formulation, should be even more sensitive to change than the abovementioned VoPE scale. The Role of Effort (RoE) scale consists of three subscales with two items (see Table 2), covering all functions of physical effort as proposed by Stähler et al. (2023). Of particular interest for this study is the subscale *Effort as Reward*, as it covers the concept of value of physical effort. Again, participants expressed their agreement with each item on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree), and an EaR Score was computed by averaging the results across both items of the subscale.

Counter Movement Jump

The Counter Movement Jump (CMJ), regarded as a natural way for humans to jump as high as possible without a run-up (Claudino et al., 2017), has been widely employed as a means to assess neuromuscular performance in humans (Buehring et al., 2010; Singh et al., 2014). Beyond being a task-specific measure of performance, the height achieved in the CMJ is indicative of the overall functional status of an individual (Busche et al., 2013; Claudino et al., 2017) and has been shown to be effective with the target population (Buehring et al., 2015). The accepted test protocol in the literature dictates the

utilization of the highest value among three maximum force jumps for evaluation (Taani et al., 2017). To conduct this assessment, the Leonardo Mechanography GRFP (Ground Reaction Force Platform) was employed, incorporating software specifications (v4.2b06.09d - Research Edition, NOVOTEC Medical GmbH, Copyright © 2013, Germany). The force plate measurement is considered a benchmark in the field (Gruber et al., 2022), providing accurate and dependable data for assessing neuromuscular performance during jump activities (Dias et al., 2011).

Isokinetic force measurement of extension & flexion of the knees

The age-related reduction in muscle size, commonly referred to as sarcopenia, is strongly correlated with a concurrent decrease in the maximum torque generated by the affected muscle areas (Kaya et al., 2011). In turn, the maximum torque can be measured by isokinetic dynamometry, which, since its inception in the 1960s (Hislop & Perrine, 1967), has evolved into a widely accepted and benchmark method for assessing human muscle function (Dirnberger et al., 2012). Measurement of peak torque of the extension and flexion of the knees in the Isomed 2000 (D&R GmbH, Gewerbering, Hemau, Germany) isokinetic dynamometer was employed. Participants completed a familiarization period during which the whole range of motion was explored. Afterwards, three extension-flexion repetitions with 15 seconds rest in between were performed. Consistent with the literature, the analysis employed only the mean maximum torque derived from the three trials (Parraca et al., 2022). In recent years, isokinetic tests have emerged as the reference method for assessing strength in older adults (Pereira et al., 2019), demonstrating excellent test-retest reliability for isokinetic strength measurements in the lower limbs (Parraca et al., 2022).

Cardiorespiratory Fitness

The exercise test maintains a crucial and integral position in cardiovascular medicine due to its high yield of diagnostic, prognostic, and functional information (Gibbons et al., 1997). Ramp testing, in particular, has gained popularity due to its ability to facilitate individualization in accordance with exercise testing guidelines (Myers & Bellin, 2000). In the study, specific protocols were implemented to cater to the unique needs of each gender group. For males, the protocol involved a gradual increase of 1 watt every 5 seconds, while for females, it followed a slightly different pace with a 1-watt increment every 6 seconds. VO2max, a key indicator of cardiorespiratory fitness, can be reliably and effectively determined during incremental (ramp) tests conducted on ergometers in the laboratory (Friedmann-Bette, 2011). The measurement protocol initiated with a 2-minute warm-up at 30 watts on the ergoselect 200 (ergoline GmbH, Bitz, Germany). Throughout the test, participants were required to maintain a cadence within the range of 60-80 rotations per minute,

sustaining this pace until reaching maximum exhaustion. To guide participants, feedback on the watts they were pedaling at was provided every 30 seconds. The participants were motivated to exert their full effort until the point of exhaustion. Participant's oxygen consumption was measured using the Ergospirometer Ergostik (Geratherm Respiratory GmbH, Bad Kissingen, Germany) with Blue Cherry program (version 1.2.2, Geratherm Respiratory GmbH, Bad Kissingen, Germany). Consistent with existing literature, the analysis focused on the maximal oxygen uptake (VO2max; Myers and Bellin, 2000).

Chair Stand Up Test

The performance in the Chair Stand Up Test (CST) has been demonstrated to have a strong correlation with the risk of falls and hip fractures among older adults (Cawthon et al., 2008). The CST serves as an assessment tool designed to evaluate the ability of individuals to rise from a chair and subsequently sit back down. Additionally, the CST provides insights into the lower body strength of individuals (Bennell et al., 2011). Participants were instructed to stand up from a standard chair with a height of approximately 43 cm to a fully extended standing position. During the test, participants folded their arms across their chest. The objective was to complete as many chair stands as possible within the 30-second time frame. The recorded outcome was the number of repetitions achieved by each individual during the specified duration (Jones et al., 1999). The CST, extensively employed in the target population, demonstrates good reliability and validity (Bennell et al., 2011).

N-Back Task

A modified version of the categorical N-back task adapted from the work of Ciesielski et al. (2006) as a classic (Kirchner, 1958) and widely used paradigm for studying working memory (Yaple & Arsalidou, 2018) was employed. In a recent study conducted by Agbangla et al. (2019), findings revealed a significant correlation between performance at higher load N-Back levels and both age and maximal oxygen consumption (VO2max). To compensate for expected age deficiencies in the sample, a continuous sequence of seven differently colored squares in the center of the screen was used. The squares had the colors red, yellow, blue, white, cyan, magenta, and green. The sequence was randomly determined and the same across all participants. Each square was displayed for two seconds. In the event that a participant issued a response before the full two-second interval had elapsed, the subsequent square in the sequence was immediately presented. The experiment consisted of three blocks of 50 stimuli with short breaks between each block. Participants were instructed to respond whenever the current stimulus matched the one presented N positions back in the sequence. The first block necessitated monitoring for a one-back position (N = 1),

with subsequent blocks incrementing N sequentially. Participants were asked to respond as quickly and accurately as possible. The experiment ended when the participants had either completed all three blocks or a total of five minutes had passed. Consistent with established evaluation protocols, performance was assessed by comparing reaction time and accuracy across varying degrees of working memory load levels (Yaple & Arsalidou, 2018). Displays were generated by a Lenovo T470s Laptop with a 14-in. (35.6 cm) FHD monitor, using 1920 * 1080 resolution graphics mode. Responses were entered via the laptop keyboard. Participants viewed this display from a distance of about 50 cm and gave responses using the Space Bar. The N-Back Task was run on PsychoPy (Version 2022.2.0).

Stroop Task

A computerized Stroop task paradigm was employed to measure the selective attention and inhibition abilities of the participants (Stroop, 1935). I focused on an ink-color & color-word incongruence task (described in Stroop, 1935) as it demonstrated robust age effects of deteriorated inhibitory ability across a multitude of studies (Kwong See & Ryan, 1995). Furthermore, research has demonstrated that performance in a Stroop Task is not only highly correlated with age but also with aerobic capacity, as measured by the maximal oxygen consumption (VO2max), in elderly individuals (Barnes et al., 2003; M. P. van Boxtel et al., 1997). Participants were asked to categorize the presented words based on their ink color as quickly and accurately as possible. Participants completed two practice blocks consisting of 20 trials each. They received feedback after every response (both trials) and were shown the assigned keys at the top of the screen (first trial). For each trial, a single stimulus was presented in the center of the screen and remained visible for two seconds, after which the stimulus was erased. Directly after a response was recorded, the next stimulus was presented. The three experimental blocks of 20 trials each were performed by the participants with short breaks between each block. The first and third experimental blocks consisted of a random series of four color words printed in congruent (first block) or incongruent (third block) ink colors. In the second experimental block, the participants were shown a random series of four German function words printed in one out of four randomly chosen ink colors. The experiment concluded after participants completed all five blocks or a total of five minutes had elapsed. Consistent with the literature, inhibitory performance was quantified by the difference of mean reaction time and accuracy of the incongruent to the congruent experimental block (Sugg & McDonald, 1994). Displays were generated by a Lenovo T470s Laptop with a 14-in. (35.6 cm) FHD monitor, using 1920 * 1080 resolution graphics mode. Responses were entered via four marked keys on the Cedrus Response Pad RB-740. Participants viewed this display from a distance of about 50 cm. The Stroop Task was run on PsychoPy (Version 2022.2.0).

Analytic Approach

The analyses were conducted with R (Version 4.3.2; R Core Team, 2023) for graphics and data preparation & JASP (Version 0.17.3; JASP Team, 2023) for Bayesian modeling. The analyses for this study were conducted using a Bayesian approach, a choice motivated by the handling of small sample sizes, as Bayesian methods are recognized for their robustness in situations involving limited data (Baldwin & Fellingham, 2013). Given that this study primarily serves as a feasibility check for Jump HIIT in the elderly population and has a pilot nature, the emphasis was placed on analyzing individual trajectories of participants rather than relying on traditional group comparisons. All analyses will be reported following the Bayesian Analysis Reporting Guidelines (BARG) as proposed by Kruschke (2021).

Assessment of Intervention Effects

An assessment of intervention effects was administered for all variables of interest in the study. The analysis strategy aligns with the expectation that the intervention will lead to improvements in various performance parameters. Upon visual examination, it became evident that the parametric assumptions of a paired t-test, specifically the assumption of Normality of Differences, were not met. In response to this, a non-parametric Wilcoxon Signed Rank test (Wilcoxon, 1992) with 1000 Markov Chain Monte Carlo (MCMC) samples was employed for the assessment of intervention effects in the analysis. Further visual examination of the data led to the decision to utilize the default prior distribution provided by JASP. This default prior distribution involves a Cauchy Distribution with a recommended spread (r) $1/\sqrt{2}$ and a location of 0 as suggested by van Doorn et al. (2020). This choice was informed by the anticipated moderate variance in effect sizes. The selected prior distribution aimed to strike a balance by allowing the capture of a broad range of effect magnitude indices while avoiding an artificial biasing of results.

In the results, key metrics will be reported to convey the findings of the analysis. These include the BF-0 (Bayes Factor), which quantifies evidence for the one-sided alternative hypothesis that the difference is smaller than 0 relative to the null hypothesis. The BF-0 provides a measure of the strength of evidence supporting the specified hypothesis. Conversely the BF0- provides a measure of the strength of evidence supporting the null hypothesis and will be reported for variables where more evidence favoring the absence of differences has been identified. In line with Harold Jeffreys' scale for interpreting Bayes factors, I assess the strength of evidence as follows: a Bayes factor (BF) between 1 and 3 suggests weak evidence, between 3 and 10 suggests moderate evidence, between 10 and 30 suggests strong evidence, and a BF greater than 30 suggests very strong evidence in favor of the alternative hypothesis (Jeffreys, 1992; Kass & Raftery, 1995; Wagenmakers et al., 2018). Additionally, the test statistic W will be provided to assess the strength of

evidence for a difference in medians. Larger values of W suggest a greater sum of ranks of positive differences, indicating that the first measurement tends to be larger than the second measurement and vice versa (van Doorn et al., 2020; Wilcoxon, 1992). Convergence of the Bayesian Signed Rank Test will be assessed using the Gelman-Rubin statistic. A value close to 1 indicates convergence, suggesting that the Markov chains have reached a stable distribution (Gelman & Rubin, 1992).

Bayesian Hierarchical Model

A Bayesian repeated measures-hierarchical linear model with simple contrasts (RM-HLM; Eid et al., 2015; Singmann and Kellen, 2020) was used for the variables of interest to assess the effect of a change in the Value of Effort on changes in physical and cognitive abilities following the Jump HIIT intervention. RM-HLM provides significant advantages over univariate analyses of variance with repeated measures, mainly because they have fewer restricted assumptions concerning the structure of the variance-covariance matrix of the dependent variable across measurement time points (Eid et al., 2015). Therefore, RM-HLM was my preferred choice for the analysis. These models are well-suited for studies that involve repeated measurements, with measurement times (Level-1) nested within individuals (Level-2; Eid et al., 2015). In the RM-HLM analysis, time served as the primary independent variable, allowing for an examination of change over time. Interpersonal differences, specifically variations in the change of the Value of Effort, were considered at the second level, and the inclusion of cross-level interaction terms further enhanced the adaptability and versatility of these models in capturing complex patterns of change and individual differences. Each participant's individual abilities and changes over time were incorporated into the model by including random slopes and random intercepts. However, the use of such a model was only considered appropriate if there was evidence of a change in a variable in the assessment of intervention effects in the first place. Models were only calculated and reported if there was evidence that a systematic change had occurred. The assumptions of RM-HLM proposed by Eid et al. (2015) and Garson (2013), specifically the normality of residuals, homoscedasticity, and linearity, were assessed through visual examination in both QQ-Plots and Residual Plots (as proposed by Frost, 2020). In the analysis, models were executed utilizing the default prior distribution offered by JASP, which employs a Normal Distribution with a recommended spread (r) of 2.5 and a location of 0 (Goodrich et al., 2020). Consistently, all models were configured with the same parameters. These parameters included 2000 iterations reserved for burn-in, a total of 4000 iterations, three chains for each model, a target average acceptance probability (adapt delta) set at 0.97, and a maximum of 10 trees evaluated during each iteration. To summarize the posterior of variables, the computed estimates, along with standard errors and boundaries of the 95%

confidence interval, will be reported. MCMC chain convergence will be assessed using R-hat values, where a value close to 1 indicates convergence, signifying that the Markov chains have reached a stable distribution (Gelman & Rubin, 1992). Additionally, MCMC chain resolution will be evaluated using Effective Sample Size (ESS) as a measure of the effective number of independent samples in Bayesian estimation (Gelman et al., 2014). A higher ESS implies a more reliable estimate. For model fit assessment, both the Watanabe-Akaike Information Criterion (WAIC; Watanabe, 2013) and the Leave-One-Out Cross-Validation (LOO; Vehtari et al., 2017) will be reported, each with their respective standard errors. While recognizing the limitations of existing information criteria, especially with smaller sample sizes like in the present study, they provide some insight into the goodness of fit of the models (Gelman et al., 2014; Vehtari et al., 2017). For both measures, a more negative value and smaller standard error indicate better model fit (Vehtari et al., 2017; Watanabe, 2013). To assess the model fit, each model was compared against a model without the nested within-individuals (Level-2) structure.

Results

Assessment of Intervention Effects

For all Assessments of Intervention Effects, the null hypothesis postulated that there was no difference in scores between the base and follow-up-measurement, and therefore H0: $\delta = 0$. The one-sided alternative hypothesis, besides for the reaction time variables in the cognitive tasks, stated that only negative values of δ were possible and assigned more prior mass to values closer to 0 than extreme values. Specifically, δ was assigned a Cauchy prior distribution with r = $1/\sqrt{2}$ truncated to allow only negative effect size values. On the contrary, in the reaction time variables, the alternative hypothesis stated that only positive values of δ were possible.

Value of Physical Effort

For the Effort as Reward (EaR) subscale, Figure 1a showes that the Bayes factor indicated evidence for the alternative hypothesis; specifically, BF-0 = 1,225. In combination with the BF-0 factor, the test statistic W = 18.5 indicated a substantially higher Effort as Reward Value in the Follow-Up than in the Baseline measurement. The R-hat Value of 1.001 showed great convergence of the MCMC chains. In the Value of Physical Effort scale, no such evidence could be found. As quantified in the BF-0 = 0.189 and the corresponding BF0- = 5.293, shown in Figure 1b and a W = 28.5. Again, an R-hat of 1.000 showed great convergence. Figure 1c displayes the individual trajectories for each participant of the EaR scores across timepoints.

Physical Abilities

Results of the Wilcoxon Signed Rank test for all physical performance tests are presented in Table 3. For the CMJ test, the Bayes Factor BF-0 = 1.215, W = 14.5, and R-hat = 1.001 indicated evidence of improvement in the Follow-Up Measurement. Participants on average jumped 0.235 m (±0.039) at baseline and 0.243 m (±0.038) after the intervention. Similarly, the Chair Stand Up Test showed improvement, with a Bayes Factor BF-0 = 29.620, W = 1.5, and R-hat = 1.008. An average of 18.67 (±6.67) repetitions were registered at baseline, while after the intervention, participants reached an average of 22.36 (±6.38) repetitions. Detailed results of both rank sum tests and individual trajectories are illustrated in Figure 2a & Figure 2b (CMJ) and Figure 2c & Figure 2d (CST) respectively.

Cognitive Abilities

There was substantial evidence in favor of the Null Hypothesis, indicating that no change had occurred over time for the Success Rates in all Cognitive Tasks (see Table 4). For the reaction time, both the Stroop Task with a BF+0 = 1.156 and W = 55, as well as the 3-Back Task with a BF+0 = 1.482 and W = 56.5, showed evidence of improvement after the intervention. Only in the 2-Back Task, there was strong evidence in favor of the H0, suggesting that no change had occurred. All three rank sum tests had great convergence with R-hat = 1.000. Detailed results of the rank sum tests and individual trajectories are illustrated in Figure 3a & Figure 3c (RT Stroop) and Figure 3b & Figure 3d (RT 3-Back) respectively. Please note that for the Stroop task, the Log (+1.5) transformed values instead of the reaction time (RT) Difference in Seconds are depicted to enhance visibility.

Bayesian Hierarchical Model

In accordance with the stipulations delineated in the Methods section, this section selectively incorporated variables for analysis within the framework of RM-HLM, focusing exclusively on those with evidence of a systematic change following the intervention. Specifically, the Change Scores of the EaR subscale were utilized, with the VoPE scale omitted from consideration. Four different outcome variables were considered: performance metrics of the CMJ and CST, as well as the RT elicited during the Stroop task and the 3-Back task. During the modeling process, it became evident that the limited number of observations precluded the computation of individual slope parameters. Consequently, the employed model formula incorporated only random intercepts for each participant.

Counter Movement Jump

A summary of the posterior distribution of the model parameters for the fixed effects can be found in Table 5. While the change from Baseline to Follow-Up only had an

estimated effect of 0.1 cm with a 95% CI ranging from – 0.008 to 0.011, the Interaction Term for Timepoint * Change Score of Effort as Reward had an estimated effect of 1.1 cm with a 95% CI ranging from 0.002 to 0.019. Therefore, the model indicated a linear increase of 1.1 cm in CMJ for every unitary increment in Change Scores observed at the Follow-Up timepoint. The model's WAIC was -127.300 (±4.244), and the LOO estimate was -121.726 (±5.714). A comparative analysis against an alternative model lacking the nested within-individuals (Level-2) structure revealed superior overall model fit for the reported model. Specifically, the alternative model exhibited a WAIC of -116.079 (±3.510) and a LOO estimate of -112.811 (±4.072). The individual trajectories of participants, taking their corresponding Change Scores into account, are visually represented in Figure 4.

Chair Stand Up Test

A summary of the posterior distribution of the model parameters for the fixed effects can be found in Table 6. Notably, the only model parameter exerting a discernible influence on the number of repetitions in the CST was the Timepoint, manifesting a fixed effect estimate of 2.743 (±1.178) repetitions, with a 95% CI spanning from 0.417 to 5.134. The interaction effect, quantified at -0.900 (±1.116), lacked robust reliability, as evidenced by its 95% CI extending from -3.158 to 1.329. This wide-ranging confidence interval implied that the effect could equally be positive or null, thus diminishing the reliability of the observed interaction effect. The model's performance was quantified through its WAIC, which stands at 132.558 (±6.124), and the LOO estimate, recorded as 136.753 (±7.380). However, a comparative examination against an alternative model lacking the within-individuals structure indicated minimal deviation in model fit. The latter model presented a WAIC of 131.883 (±6.748) and a LOO estimate of 136.253 (±8.598). The individual trajectories of participants, taking their corresponding Change Scores into account, are visually represented in Figure 5.

RT Difference in Stroop Task

A summary of the posterior distribution of the model parameters for the fixed effects can be found in Table 7. In this model, no parameter could be identified as having a reliable influence on the reaction time difference between incongruent and congruent trials. The interaction effect of Change Score in EaR and Timepoint registered at -0.240 (±0.545), which indicated a potentially positive effect. However, the reliability of this effect was challenged by the 95% CI, which ranges from -1,325 to 0,848. Concerning model fit, the current model demonstrated comparable performance to an alternative model devoid of the nested structure. The model in question yielded a WAIC of 109.791 (±17.309) and a LOO estimate of 111.386 (±17.632). In contrast, the alternative model, which lacked the nested

structure, reported a WAIC of 108.429 (±20.759) and a LOO estimate of 111.456 (±23.032). The individual trajectories of participants, incorporating their respective Change Scores are visualized in Figure 6. Please note that, the Log (+1,5) transformed values instead of the RT Difference in Seconds are depicted to enhance visibility.

RT in 3 – Back Task

A summary of the posterior distribution of the model parameters for the fixed effects can be found in Table 8. Despite all parameters suggesting a marginal positive effect, none of them exhibited reliable significance when considering the associated Standard Errors and 95% CI. In this context, the model without the nested structure demonstrated superior performance compared to the reported model. The former yielded a WAIC of -36,886 (±5,601) and an estimated LOO score of -33,989 (±6,239). In contrast, the alternative model, devoid of the nested structure, reported a WAIC of -40,788 (±5,712) and an estimated LOO score of -38,461 (±6,203). The individual trajectories of participants, taking their corresponding Change Scores into account, are visually represented in Figure 7.

Discussion

Key Insights

Value of Effort

The Bayes Factor BF-0 of 1.225 associated with the Effort as Reward variable indicates weak or anecdotal evidence in support of the alternative hypothesis, suggesting an increase in the perceived value of effort following the Jump HIIT Intervention. This outcome implies that the observed data are approximately 1.2 times more probable under the alternative hypothesis (H1) than under the null hypothesis (H0). In contrast, the Bayes Factor BF0- of 5.293 for the Value of Physical Effort scale suggests that the data are 5.29 times more likely to occur under H0, indicating no significant alterations during the intervention. Consequently, I infer that no discernible changes in the trait value of effort have transpired through the intervention. However, the more change-sensitive state measure of prospective and retrospective Effort as Reward indicates an effect of the Jump HIIT Intervention on participants' valuing of effort. To specify, it is plausible that the repeated pairing of high effort exertion with rewards has enhanced the perceived value of effort itself.

Physical Abilities

The Bayes Factor BF-0 of 29.619 linked to the repetitions in the Chair Stand Up Test offers strong evidence, on the Jeffreys scale, of an increase in performance at follow-up.

This strong evidence implies that the observed data are decisively more likely to occur under the alternative hypothesis, indicating a notable improvement in performance. Likewise, a positive effect, albeit with weak or anecdotal evidence, was observed for maximum jump height during the CMJ Follow-Up, with a Bayes factor BF-0 of 1.215. This suggests that the observed data are approximately 1.2 times more likely to be in line with the alternative hypothesis. No systematic evidence of enhanced performance in other physical ability variables was found. Nonetheless, the observed increase in CMJ height and repetitions in the CST holds great importance. The direct similarity in movement between these tasks and the Jump HIIT Intervention renders it plausible that positive effects would be most readily detectable in these specific metrics. Furthermore, the CST's explicit focus on assessing the risk-mitigated relevance of falls within participants' everyday life underscores the practical significance and impact of the Jump HIIT Intervention on enhancing participants' physical ability, particularly in contexts relevant to their daily functioning and fall prevention.

Cognitive Abilities

Similar to the more indirect physical performance measures, the anticipated increase in cognitive abilities relies on indirect effects resulting from enhanced cardiorespiratory fitness and a broadened valuation of effort across domains induced by the Jump HIIT. Given these indirect pathways and the small sample size inherent in the pilot and feasibility study design, it appears plausible that evidence for systematic effects across participants may be obstructed. Across all cognitive tests, there was no discernible effect on success rates observed across different timepoints. However, the presence of weak or anecdotal evidence for a quicker reaction time in both the Stroop Interference Task and the 3-Back Task, while inconclusive, provides some positive indications. This suggests that, albeit tentatively, the Jump HIIT Intervention may exert a positive influence on cognitive abilities, even though conclusive evidence is limited by the study's inherent constraints.

Bayesian Hierarchical Model

As previously stated in the methods section, models were computed only for variables with indication of systematic improvement over time. Consequently, the change in Effort as Reward was integrated into the nested, second level, within-person structure. Furthermore, to test the hypothesis positing that a positive change in the valuing of effort correlates with improvements in physical and cognitive abilities among participants, models were constructed to predict performance across variables wherein evidence of heightened performance was discerned. Specifically, the CMJ and Chair Stand Up Test emerged as representative of physical abilities, while the reaction time in the Stroop and 3-Back Task was selected as indicative of cognitive abilities.

The CMJ prediction model presented strong support for the hypothesis, displaying a linear increase of 1.1 cm in CMJ for each unitary increment in change scores observed at the Follow-Up timepoint. Of particular importance, no reliable estimates were observed for either Change Score or Timepoint alone, emphasising the relevance of the interaction term. This alignment with the hypothesis suggests that an increase in the valuation of effort may enhance the efficacy of the Jump HIIT intervention through mechanisms hitherto described exclusively in the cognitive effort literature. Such processes include the propensity to engage in more effortful leisure tasks (Therriault et al., 2015) and a reduced need for external incentives to motivate oneself for high-effort exertion (Sandra & Otto, 2018) in individuals with a higher valuation of cognitive effort. Additionally, the corroborative findings of Hess et al. (2012), specifically that a greater change in the value of cognitive effort (measured by the change in Need for Cognition), predicted heightened cognitive abilities in a longitudinal study design, lend further support to this premise. Extending this rationale to the physical domain, I posit that participants experiencing an increase in the valuing of physical effort may exhibit similar behavioural patterns. This, in turn, offers a plausible explanation for the heightened benefits of the intervention, as heightened willingness to exert effort could amplify the anticipated effects of the intervention.

Despite the promising effects observed in the CMJ model, the findings from the remaining models present a mix of results. Specifically, the models for reaction time in the cognitive tests suggested a positive interaction effect, while the model for the CST indicated a contrasting, negative effect. However, a commonality among all these models is the presence of high standard errors and wide 95% CIs, rendering reliable statements about effect size and direction challenging. These limitations are presumably attributed, once again, to the inherent low statistical power stemming from the study's small sample size. My findings suggest that the most reliable effects are observed in tasks closely related to the Jump HIIT Intervention, while weaker or no effects are noted for tasks indirectly influenced by the exercises. This pattern indicates that valuing of effort is more pronounced in tasks closely resembling the original effort type.

General Discussion

In this study, preliminary evidence elucidating the moderating role of the Value of Physical Effort in the effectiveness of a 12-week Jump HIIT Intervention among older adults has been assembled. The results suggest that this novel training intervention is not only feasible for this demographic but also holds promise as an moderately effective training intervention for augmenting the physical fitness of the target population. As extensively discussed earlier, the outcomes for physical fitness variables presented mixed results. It is noteworthy that the two variables most closely aligned in movement with the Jump

HIIT Intervention yielded the most promising indications of effectiveness, aligning with expectations for a pilot study. While acknowledging the mixed results, the Jump HIIT Intervention appears promising as an exercise intervention. Its feasibility for older adults, coupled with observed beneficial effects on select physical performance variables, suggests a potential avenue for enhancing physical fitness in this demographic.

Moreover, my investigation revealed an increase in the state-based measure of value of physical effort over the course of the intervention, thus partially substantiating the core hypothesis. This supports the notion of an augmented value of physical effort through repeated experiences of high efforts coupled with rewards. Although the training intervention did not induce significant changes in the more trait-based scores of the Value of Physical Effort (VoPE) scale, the Effort as Reward (EaR) subscale of the Role of Effort scale, which is more sensitive to change and reflects a state-based assessment, did align with my hypothesis. This preliminary evidence suggests that the Value of Effort, much like its cognitive counterpart, the Need for Cognition, is a modifiable construct that can be influenced through reinforcement learning (Hess et al., 2012; H. Lin et al., 2021). Although this study provides initial insights into the relationship and modifiability of the value of physical effort, it is necessary to conduct further research to clarify the underlying mechanisms and specific conditions conducive to its modification. I propose the Theory of Learned Industriousness as a probable mechanism, informed by the literature and supported by the evidence presented here.

Regarding the influence of the value of physical effort on the physical fitness, my findings suggest that a positive change in valuing of effort can potentially serve as a moderator in the training success achieved through the intervention. A positive change in the value of physical effort was associated with higher jump height in the CMJ. Despite the non-uniformity of effects across all models, with the CMJ model yielding the most reliable results and the model for the CST providing inconclusive evidence, the gathered evidence suggests that a positive change in the valuing of effort can potentially exert a beneficial influence over the effectiveness of a Jump HIIT Intervention. This aligns with my hypothesis that a positive change in the valuing of physical effort is linked with greater intervention effects, resembling the findings within the cognitive domain. These parallels further support the notion that the two constructs, although distinct in the domain, are closely linked regarding underlying processes and phenomena.

The cognitive tasks yielded inconsistent findings, and no compelling evidence was found for the assessment of intervention effects. While reaction time provided the most promising indication of a positive change among the cognitive measures, no reliable evidence was uncovered. In the RM-HLM analysis, where a shorter reaction time on the 3-Back task and improved inhibitory abilities, as indicated by the time difference between

congruent and incongruent trials on the Stroop task, were associated with a higher change in the value of physical effort, the variance of parameter estimates was so substantial that it cannot be ruled out that the true effect is simply zero. Typically, both success rate and reaction time (differences) are considered when assessing the N-Back and Stroop Task (Sugg & McDonald, 1994; Yaple & Arsalidou, 2018). The presented evidence, alongside its inherent uncertainty due to high variability in parameter estimation, should be approached with caution, providing only a slight positive indication of improvement in cognitive abilities. These inconsistent patterns align with the literature on the across-domain generalization of the valuing of effort, where, despite the theoretical relatedness of both constructs, no decisive evidence for or against across-domain generalization has been established (Bustamante et al., 2014; Chong et al., 2018; Wolff et al., 2023). Hence, I advocate for further investigations into across-domain generalization, employing new paradigms to directly test the hypothesis that a greater valuing of effort in one domain is associated not only with improved performance in that domain but also with a domain-unspecific performance increase. From the preliminary evidence in this study, it appears that, despite the hypothesized generalization, the magnitude of the moderating influence may differ between within-domain and across-domain effects.

Limitations

This study was planned and executed as a feasibility pilot study, aimed at assessing the viability of the newly developed Jump HIIT Intervention among older adults. The principal objective was to gain preliminary insights into the feasibility of this physical exercise intervention, with the ultimate goal of determining whether a full randomized control trial study is warranted. Given the piloting nature of both the Jump HIIT Intervention and the examination of the value of physical effort in this context, a myriad of challenges had to be navigated. The pilot design, involving a modest cohort of 17 participants at the study's inception, presented a distinct challenge as statistical power, particularly in scenarios involving smaller effects or greater variability between participants, could become a limiting factor. To mitigate this concern, I strategically employed a Bayesian approach, recognized for its advantages in addressing challenges associated with small sample sizes (Baldwin & Fellingham, 2013). Additionally, my emphasis on individual trajectories, both in the visualization of results and within the RM-HLM framework, served as a complementary strategy to navigate the inherent limitations of the study's design.

The age of the cohort, coupled with entirely voluntary participation without the prospect of compensation, introduced the potential for dropout to serve as a confounding factor. As anticipated, five participants were unable to complete the study, representing an approximate dropout rate of 30%. While no consistent pattern for dropouts were revealed,

with participants attributing reasons such as unrelated health issues, including instances of Covid-19 infection, it remains a possibility that the high dropout rate could impact the conclusiveness of the study's results.

In terms of the study design, it is acknowledged that certain challenges related to the research questions persist. Given the primary focus of this study on feasibility assessment, some aspects related to the investigation of Learned Industriousness were not incorporated at the study's inception due to considerations at that time. The Learned Industriousness Theory posits that through the repeated pairing of high effort exertion and rewards, effort itself can become a secondary reinforcer and, consequently, can be valued in its own right (Eisenberger, 1992). My hypotheses are grounded in this theory, asserting that participants will perceive the Jump HIIT intervention as both highly physically effortful and rewarding. While the assumption regarding the perceived effort is supported by existing literature (Borg, 1982; Kramer et al., 2019; Robertson & Noble, 1997), an ideal study design would have included measures such as self-reports or physiological assessments to ensure that participants' experiences align with these assumptions. For future studies, I recommend implementing a self-report utilizing the Rate of Perceived Exertion scale developed by Borg (1982). This scale prompts participants to rate their perceived exertion on a scale from 6 to 20, with verbal anchors ranging from "no exertion at all" (equals 6) to "maximal exertion" (equals 20). The scale, revised and translated into German (Löllgen, 2004), has demonstrated reliability, even among older adults (Löllgen, 2004), and exhibits high reliability across various age cohorts and physical tasks (Haddad et al., 2017). Furthermore, it has been established that physiological markers, such as heart rate, serve as reliable indicators of perceived exertion and exhibit a strong correlation with self-reported responses (Borg, 1982; Robertson & Noble, 1997). Incorporating these measures in future studies would enhance the comprehensiveness and validity of the investigation into participants' experiences during physical exertion. Additionally, the perception of rewards associated with the Jump HIIT, although grounded in a reasonable assumption supported by literature (Berg et al., 2015), could be further validated in future study designs by incorporating a self-report measure to confirm the accuracy of these assumptions. Currently, to the best of my knowledge, no questionnaire directly assessing the rewards people experience during a task has been published. However, it would be feasible to adapt an existing questionnaire, such as the Physical Activity and Leisure Motivation scale (PALMS), which, in its original form, evaluates motives for participating in physical activity. The modification could involve querying participants to what extent they perceive the different aspects covered by the PALMS, specifically, mastery, enjoyment, psychological condition, physical condition, appearance, others' expectations, affiliation, and competition/ego—as rewarding (Molanorouzi et al., 2014). In summary, I advocate for future research endeavours in the

field of Learned Industriousness to not only replicate this study design but also to enhance certain aspects. Specifically, I recommend incorporating checks to validate assumptions about perceived effortfulness and rewards during the intervention. This refinement aims to bolster the explanatory power and validity of the conclusions drawn from the study, contributing to a more robust understanding of the interplay between effort valuation and physical exercise interventions.

Exploring the differing functions of effort, as delineated by Stähler et al. (2023), could offer valuable insights into the efficacy of a Jump HIIT intervention. A more in-depth analysis of individual trajectories pertaining not only to effort as reward but also to effort as instrument and effort as value added has the potential to enhance the understanding of the development of a value of physical effort and the underlying mechanisms. Such an investigation may further illuminate the dynamic interplay among these various functions of effort, their temporal evolution, and their impact on the effectiveness of a Jump HIIT intervention. Unfortunately, the exploration of this intriguing research question was constrained by the limitations in sample size delineated earlier and the anticipated complexity of the relationships. However, it is recommended that future investigations in the realm of the Value of Effort delve into these intricate relationships to advance the comprehension of the nuanced influences exerted by the different functions of effort, their temporal dynamics, and their collective effect on the effectiveness of Jump HIIT interventions.

While the study design incorporated yields exceptional generalizability due to the field study nature of the Jump HIIT conduction, characterized by a single explanatory session in the laboratory at the study's initiation and subsequent exercises executed at participants' discretion with only a printed training plan for oversight, these design choices might hinder the emergence of greater intervention effects in the domain of value of physical effort. This limitation can be attributed to variability in the execution of exercises and the true total training volume. The design choices were rationalized within the context of the study's focus on assessing the feasibility of the Jump HIIT Intervention with aspirations for broad applicability among elderly individuals. However, they may obscure potential evidence for the questions addressed in this paper. While direct testing in the application area is valuable for the meaningfulness of the findings, a more controlled laboratory setting could be advantageous for investigating potential small effect sizes and laying a solid foundation for further research in this novel field. In a controlled laboratory study, the direct rewarding of high effort, such as with monetary incentives, would be feasible, potentially enhancing the learning process as described in the Learned Industriousness Theory. Reducing reliance on indirect rewards, as anticipated in this study (e.g., opportunities for social interaction and hedonic rewards), could be particularly beneficial for generalizing effort valuing across tasks within a domain and across domains.

The field study character of the Jump HIIT Intervention in this study also introduced variability and potential unreliability in the data regarding the training load of participants. Since the training load was monitored solely through self-reporting, wherein participants recorded the number of minutes spent on each training session on the planning sheet, there is a possibility that some participants provided socially desirable information. Furthermore, the available data, even when not confounded, displayed significant variability in the total training load among participants, indicating that not everyone experienced the same opportunities for high effort & reward coupling. Although a comprehensive analysis of the effect of total training load was conducted by Campoverde (2023) in his Master's Thesis and will not be elaborated upon here, it is noteworthy that total training load could potentially serve as a confounding factor, both in assessing the overall effectiveness of the Jump HIIT Intervention and in relation to the Value of Physical Effort.

Conclusion

In conclusion, I contend that the evidence collected in this pilot study, while preliminary due to the Limitations delineated above, lends support to the notion that the *Value of Physical Effort* could serve as a moderator for the effectiveness of a training intervention aimed at enhancing physical and potentially cognitive abilities in the elderly. The findings revealed not only the potential for an augmentation in the Value of Physical Effort during a Jump HIIT intervention but also indicated that such an increase could yield potentially beneficial effects on the intervention's effectiveness. The RM-HLM analysis demonstrated a higher jump height in individuals exhibiting a positive change in the Effort as Reward subscale. Furthermore, the results presented preliminary evidence suggesting an improved reaction time in certain cognitive tasks associated with an increase in the Value of Physical Effort. This perspective is particularly relevant in addressing the associated health risks linked to decreased functionality of the lower limbs, diminished Cardiorespiratory Fitness, and Cognitive Impairment. Consequently, I advocate for further research in the field of the Value of Physical Effort to comprehensively understand the construct and incorporate it into broader frameworks for planning and conducting health-related physical fitness interventions. The incorporation of such an approach could potentially contribute to a more nuanced comprehension of the comparatively unsatisfactory longevity and smaller effect sizes observed in exercise interventions and meta-reviews (Alessy et al., 2023; Brasure et al., 2018; van der Bij et al., 2002). This, in turn, has the potential to not only enhance the understanding of human perceptions of effort but also directly inform applications in health and sport psychology.

References

Agbangla, N. F., Audiffren, M., Pylouster, J., & Albinet, C. T. (2019). Working memory, cognitive load and cardiorespiratory fitness: Testing the CRUNCH model with near-infrared spectroscopy. *Brain sciences*, *9*(2). https://doi.org/10.3390/brainsci9020038

Alessy, S. A., Malkin, J. D., Finkelstein, E. A., AlAhmed, R., Baattaiah, B. A., Evenson, K. R., Rakic, S., Cetinkaya, V., Herbst, C. H., Al-Hazzaa, H. M., & Alqahtani, S. A. (2023). Effectiveness of interventions promoting physical activity and reducing sedentary behavior in community-dwelling older adults: An umbrella review with application to saudi arabia. *Journal of epidemiology and global health*, *13*(2), 361–373. https://doi.org/10.1007/s44197-023-00111-6

Arulpragasam, A. R., Cooper, J. A., Nuutinen, M. R., & Treadway, M. T. (2018). Corticoinsular circuits encode subjective value expectation and violation for effortful goal-directed behavior. *Proceedings of the National Academy of Sciences*, *115*(22), 233–242. https://doi.org/10.1073/pnas.1800444115

Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review*, *64*(6), 359–372. https://doi.org/10.1037/h0043445

Baer, L. H., Tabri, N., Blair, M., Bye, D., Li, K. Z. H., & Pushkar, D. (2013). Longitudinal associations of need for cognition, cognitive activity, and depressive symptomatology with cognitive function in recent retirees. *The journals of gerontology. Series B, Psychological sciences and social sciences*, *68*(5), 655–664. https://doi.org/10.1093/geronb/gbs112

Baldwin, S. A., & Fellingham, G. W. (2013). Bayesian methods for the analysis of small sample multilevel data with a complex variance structure. *Psychological Methods*, *18*(2), 151–164. https://doi.org/10.1037/a0030642

Barnes, D. E., Yaffe, K., Satariano, W. A., & Tager, I. B. (2003). A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. *Journal of the American Geriatrics Society*, *51*(4), 459–465. https://doi.org/10.1046/j.1532-5415.2003.51153.x

Baumgart, M., Snyder, H. M., Carrillo, M. C., Fazio, S., Kim, H., & Johns, H. (2015). Summary of the evidence on modifiable risk factors for cognitive decline and dementia: A population-based perspective. *Alzheimer's & dementia : the journal of the Alzheimer's Association*, *11*(6), 718–726. https://doi.org/10.1016/j.jalz.2015.05.016

Bennell, K., Dobson, F., & Hinman, R. (2011). Measures of physical performance assessments: Self-Paced Walk Test (SPWT), Stair Climb Test (SCT), Six-Minute Walk Test (6MWT), Chair Stand Test (CST), Timed Up & Go (TUG), Sock Test, Lift

and Carry Test (LCT), and Car Task. *Arthritis care & research*, *63*, S350–70. https://doi.org/10.1002/acr.20538

Berg, B. K., Warner, S., & Das, B. M. (2015). What about sport? A public health perspective on leisure-time physical activity. *Sport Management Review*, *18*(1), 20–31. https://doi.org/10.1016/j.smr.2014.09.005

Bernacer, J., Martinez-Valbuena, I., Martinez, M., Pujol, N., Luis, E. O., Ramirez-Castillo, D., & Pastor, M. A. (2019). An amygdala-cingulate network underpins changes in effort-based decision making after a fitness program. *NeuroImage*, *203*, Article e116181. https://doi.org/10.1016/j.neuroimage.2019.116181

Białaszek, W., Marcowski, P., & Ostaszewski, P. (2017). Physical and cognitive effort discounting across different reward magnitudes: Tests of discounting models. *PLOS ONE*, *12*(7), Article e0182353. https://doi.org/10.1371/journal.pone.0182353

Bieleke, M., Stähler, J., Wolff, W., & Schüler, J. (2023). *Development and validation of the Value of Physical Effort (VoPE) scale* [PsyArXiv]. https://doi.org/10.31234/osf.io/pqw26

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377–381. https://doi.org/10.1249/00005768-198205000-00012

Botvinick, M. M., & Rosen, Z. B. (2009). Anticipation of cognitive demand during decision-making. *Psychological Research PRPF*, *73*, 835–842. https://doi.org/10.1007/s00426-008-0197-8

Brasure, M., Desai, P., Davila, H., Nelson, V. A., Calvert, C., Jutkowitz, E., Butler, M., Fink, H. A., Ratner, E., Hemmy, L. S., McCarten, J. R., Barclay, T. R., & Kane, R. L. (2018). Physical activity interventions in preventing cognitive decline and alzheimer-type dementia: A systematic review. *Annals of internal medicine*, *168*(1), 30–38. https://doi.org/10.7326/M17-1528

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual review of psychology*, *40*(1), 109–131. https://doi.org/10.1146/annurev.ps.40.020189.000545

Brehm, J. W., Wright, R. A., Solomon, S., Silka, L., & Greenberg, J. (1983). Perceived difficulty, energization, and the magnitude of goal valence. *Journal of Experimental Social Psychology*, *19*(1), 21–48. https://doi.org/10.1016/0022-1031(83)90003-3

Buchman, A. S., Wilson, R. S., Boyle, P. A., Tang, Y., Fleischman, D. A., & Bennett, D. A. (2007). Physical activity and leg strength predict decline in mobility performance in older persons. *Journal of the American Geriatrics Society*, *55*(10), 1618–1623. https://doi.org/10.1111/j.1532-5415.2007.01359.x

Buehring, B., Krueger, D., Fidler, E., Gangnon, R., Heiderscheit, B., & Binkley, N. (2015). Reproducibility of jumping mechanography and traditional measures of physical and

muscle function in older adults. *Osteoporosis Int*, *26*(2), 819–825. https://doi.org/10.1007/s00198-014-2983-z

Buehring, B., Krueger, D., & Binkley, N. (2010). Jumping mechanography: A potential tool for sarcopenia evaluation in older individuals. *Journal of Clinical Densitometry*, *13*(3), 283–291. https://doi.org/10.1016/j.jocd.2010.04.002

Busche, P., Rawer, R., Rakhimi, N., Lang, I., & Martin, D. D. (2013). Mechanography in childhood: References for force and power in counter movement jumps and chair rising tests. *Journal of musculoskeletal & neuronal interactions*, *13*(2), 213–226.

Bustamante, E. E., Davis, C. L., & Marquez, D. X. (2014). A test of learned industriousness in the physical activity domain. *International journal of psychological studies*, *6*(4), 12–25. https://doi.org/10.5539/ijps.v6n4p12

Cacioppo, J. T., Petty, R. E., Feinstein, J. A., & Jarvis, W. B. G. (1996). Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological Bulletin*, *119*(2), 197–253. https://doi.org/10.1037/0033-2909.119.2.197

Cambridge-Dictionary. (n.d.). Sport. *Cambridge Dictonary*. Retrieved Dezember 07, 2023, from https://dictionary.cambridge.org/dictionary/english/sport.

Campoverde, F. (2023). *Effects of hiit jump training in senior tennis players* [Unpublished master's thesis]. University of Konstanz.

Cawthon, P. M., Fullman, R. L., Marshall, L., Mackey, D. C., Fink, H. A., Cauley, J. A., Cummings, S. R., Orwoll, E. S., & Ensrud, K. E. (2008). Physical performance and risk of hip fractures in older men. *Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research*, *23*(7), 1037–1044. https://doi.org/10.1359/jbmr.080227

Chong, T. T.-J., Apps, M., Giehl, K., Sillence, A., Grima, L. L., & Husain, M. (2017). Neurocomputational mechanisms underlying subjective valuation of effort costs. *PLoS biology*, *15*(2), Article e1002598. https://doi.org/10.1371/journal.pbio.1002598

Chong, T. T.-J., Apps, M. A. J., Giehl, K., Hall, S., Clifton, C. H., & Husain, M. (2018). Computational modelling reveals distinct patterns of cognitive and physical motivation in elite athletes. *Scientific reports*, *8*(1), Article e11888. https://doi.org/10.1038/s41598-018-30220-3

Ciesielski, K. T., Lesnik, P. G., Savoy, R. L., Grant, E. P., & Ahlfors, S. P. (2006). Developmental neural networks in children performing a categorical n-back task. *NeuroImage*, *33*(3), 980–990. https://doi.org/10.1016/j.neuroimage.2006.07.028

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor

neuromuscular status: A meta-analysis. *Journal of science and medicine in sport*, *20*(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Cocker, P. J., Hosking, J. G., Benoit, J., & Winstanley, C. A. (2012). Sensitivity to cognitive effort mediates psychostimulant effects on a novel rodent cost/benefit decision-making task. *Neuropsychopharmacology : official publication of the American College of Neuropsychopharmacology*, *37*(8), 1825–1837. https://doi.org/10.1038/npp.2012.30

Comas-Herrera, A., Wittenberg, R., Pickard, L., & Knapp, M. (2007). Cognitive impairment in older people: Future demand for long-term care services and the associated costs. *International journal of geriatric psychiatry*, *22*(10), 1037–1045. https://doi.org/10.1002/gps.1830

Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., & Lubans, D. R. (2015). High-intensity interval training for improving health-related fitness in adolescents: A systematic review and meta-analysis. *British journal of sports medicine*, *49*(19), 1253–1261. https://doi.org/10.1136/bjsports-2014-094490

Costigan, S. A., Eather, N., Plotnikoff, R. C., Hillman, C. H., & Lubans, D. R. (2016). High-intensity interval training for cognitive and mental health in adolescents. *Medicine and science in sports and exercise*, *48*(10), 1985–1993. https://doi.org/10.1249/MSS.0000000000000993

Crespi, L. P. (1942). Quantitative variation of incentive and performance in the white rat. *The American Journal of Psychology*, *55*(4), 467–517. https://doi.org/10.2307/1417120

de Morree, H. M., & Marcora, S. M. (2010). The face of effort: Frowning muscle activity reflects effort during a physical task. *Biological psychology*, *85*(3), 377–382. https://doi.org/10.1016/j.biopsycho.2010.08.009

Deschenes, M. R. (2004). Effects of aging on muscle fibre type and size. *Sports medicine*, *34*(12), 809–824. https://doi.org/10.2165/00007256-200434120-00002

Dias, J. A., Dal Pupo, J., Reis, D. C., Borges, L., Santos, S. G., Moro, A. R. P., & Borges, N. G. (2011). Validity of two methods for estimation of vertical jump height. *Journal of strength and conditioning research*, *25*(7), 2034–2039. https://doi.org/10.1519/JSC.0b013e3181e73f6e

Directorate General for Economic and Financial Affairs. (2021). *The 2021 ageing report* (Vol. 148). Publications Office of the European Union. https://doi.org/10.2765/84455

Dirnberger, J., Wiesinger, H.-P., Kösters, A., & Müller, E. (2012). Reproducibility for isometric and isokinetic maximum knee flexion and extension measurements using the

isomed 2000-dynamometer. *Isokinetics and Exercise Science*, *20*(3), 149–153. https://doi.org/10.3233/IES-2012-0451

Eid, M., Gollwitzer, M., & Schmitt, M. (2015). *Statistik und Forschungsmethoden* (4.). Beltz. https://doi.org/10.17877/DE290R-12739

Eisenberger, R. (1992). Learned industriousness. *Psychological Review*, *99*(2), 248–267. https://doi.org/10.1037/0033-295X.99.2.248

Eisenberger, R., & Adornetto, M. (1986). Generalized self-control of delay and effort. *Journal of Personality and Social Psychology*, *51*(5), 1020–1031. https://doi.org/10.1037/0022-3514.51.5.1020

Eisenberger, R., & Leonard, J. M. (1980). Effects of conceptual task difficulty on generalized persistence. *The American Journal of Psychology*, *93*(2), 285–298. https://doi.org/10.2307/1422233

Eisenberger, R., & Masterson, F. A. (1983). Required high effort increases subsequent persistence and reduces cheating. *Journal of Personality and Social Psychology*, *44*(3), 593–599. https://doi.org/10.1037/0022-3514.44.3.593

Eisenberger, R., Carlson, J., Guile, M., & Shapiro, N. (1979). Transfer of effort across behaviors. *Learning and Motivation*, *10*(2), 178–197. https://doi.org/10.1016/0023-9690(79)90043-2

Fleg, J. L., Morrell, C. H., Bos, A. G., Brant, L. J., Talbot, L. A., Wright, J. G., & Lakatta, E. G. (2005). Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation*, *112*(5), 674–682. https://doi.org/10.1161/CIRCULATIONAHA.105.545459

Frederick, S. (2005). Cognitive reflection and decision making. *Journal of Economic Perspectives*, (4), 25–42. https://doi.org/http://doi.org/10.1257/089533005775196732

Friedmann-Bette, B. (2011). Die Spiroergometrie in der sportmedizinischen Leistungsdiagnostik. *Deutsche Zeitschrift für Sportmedizin*, *62*(1). https://www.germanjournalsportsmedicine.com/fileadmin/content/archiv2011/heft01/spomed_1_2011_pdfe_02/uebersicht_bette_korr_bg_neu.pdf

Frost, J. (2020). *Regression analysis: An intuitive guide for using and interpreting linear models*. Statistics By Jim Publishing.

Garson, G. (2013). *Hierarchical linear modeling: Guide and applications*. Sage. https://doi.org/10.4135/9781483384450

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2014). *Bayesian data analysis* (3rd ed.). Chapman and Hall/CRC. https://doi.org/10.1201/b16018

Gelman, A., & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science*, *7*(4). https://doi.org/10.1214/ss/1177011136

Gibbons, R. J., Balady, G. J., Beasley, J. W., Bricker, J. T., Duvernoy, W. F., Froelicher, V. F., Mark, D. B., Marwick, T. H., McCallister, B. D., Thompson, P. D., Winters, W. L., Yanowitz, F. G., Ritchie, J. L., Cheitlin, M. D., Eagle, K. A., Gardner, T. J., Garson, A., Lewis, R. P., O'Rourke, R. A., & Ryan, T. J. (1997). ACC/AHA Guidelines for Exercise Testing. A report of the American College of Cardiology/American Heart Association. *Journal of the American College of Cardiology*, *30*(1), 260–311. https://doi.org/10.1016/S0735-1097(97)00150-2

Goodrich, B., Gabry, J., Ali, I., & S, B. (2020). Rstanarm: Bayesian applied regression modeling via stan. https://mc-stan.org/rstanarm

Grèzes, J., Frith, C., & Passingham, R. E. (2004). Brain mechanisms for inferring deceit in the actions of others. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, *24*(24), 5500–5505. https://doi.org/10.1523/JNEUROSCI.0219-04.2004

Gruber, M., Peltonen, J., Bartsch, J., & Barzyk, P. (2022). The validity and reliability of counter movement jump height measured with the Polar Vantage V2 sports watch. *Frontiers in sports and active living*, *4*, Article e1013360. https://doi.org/10.3389/fspor.2022.1013360

Guralnik, J. M., Ferrucci, L., Pieper, C. F., Leveille, S. G., Markides, K. S., Ostir, G. V., Studenski, S., Berkman, L. F., & Wallace, R. B. (2000). Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *The journals of gerontology. Series A, Biological sciences and medical sciences*, *55*(4), 221–231. https://doi.org/10.1093/gerona/55.4.m221

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-rpe method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Frontiers in neuroscience*, *11*, 612. https://doi.org/10.3389/fnins.2017.00612

Haynos, A. F., Koithan, E., & Hagan, K. E. (2023). Learned industriousness as a translational mechanism in anorexia nervosa. *Nature reviews psychology*, *2*(2), 112–126. https://doi.org/10.1038/s44159-022-00134-z

Henderlong Corpus, J., & Lepper, M. R. (2007). The effects of person versus performance praise on children's motivation: Gender and age as moderating factors. *Educational psychology*, *27*(4), 487–508. https://doi.org/10.1080/01443410601159852

Herrebrøden, H., Espeseth, T., & Bishop, L. (2023). Mental effort in elite and nonelite rowers. *Journal of sport & exercise psychology*, *45*(4), 208–223. https://doi.org/10.1123/jsep.2022-0164

Hess, T. M., Emery, L., & Neupert, S. D. (2012). Longitudinal relationships between resources, motivation, and functioning. *The journals of gerontology. Series B, Psy-*

chological sciences and social sciences, *67*(3), 299–308. https://doi.org/10.1093/geronb/gbr100

Hislop, H. J., & Perrine, J. (1967). The isokinetic concept of exercise. *Physical therapy*, *47*(1), 114–117. https://doi.org/10.1093/ptj/47.1.114

Hull, C. (1943). *Principles of behavior: An introduction to behavior theory,* Appleton-Century-Croft.

Inzlicht, M., Shenhav, A., & Olivola, C. Y. (2018). The effort paradox: Effort is both costly and valued. *Trends in cognitive sciences*, *22*(4), 337–349. https://doi.org/10.1016/j.tics.2018.01.007

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*, *50*(5), 889–896. https://doi.org/10.1046/j.1532-5415.2002.50216.x

JASP Team. (2023). *JASP (Version 0.18.2)[Computer software]*. https://jasp-stats.org/

Jeffreys, H. (1992). The theory of probability. *Nature*, *109*, 132–133. https://doi.org/https://doi.org/10.1038/109132a0

Jones, C. J., Rikli, R. E., & Beam, W. C. (1999). A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research quarterly for exercise and sport*, *70*(2), 113–119. https://doi.org/10.1080/02701367.1999.10608028

Jonker, L., Elferink-Gemser, M. T., Toering, T. T., Lyons, J., & Visscher, C. (2010). Academic performance and self-regulatory skills in elite youth soccer players. *Journal of sports sciences*, *28*(14), 1605–1614. https://doi.org/10.1080/02640414.2010.516270

Kass, R. E., & Raftery, A. E. (1995). Bayes factors. *Journal of the American Statistical Association*, *90*(430), 773–795. https://doi.org/10.1080/01621459.1995.10476572

Kaya, D., Citaker, S., Kerimoglu, U., Atay, O. A., Nyland, J., Callaghan, M., Yakut, Y., Yüksel, I., & Doral, M. N. (2011). Women with patellofemoral pain syndrome have quadriceps femoris volume and strength deficiency. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *19*(2), 242–247. https://doi.org/10.1007/s00167-010-1290-2

Kilpatrick, M. W., Jung, M. E., & Little, J. P. (2014). High-intensity interval training. *ACSM'S Health & Fitness Journal*, *18*(5), 11–16. https://doi.org/10.1249/FIT.0000000000000067

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of experimental psychology*, *55*(4), 352–358. https://doi.org/10.1037/h0043688

Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of experimental psychology. General*, *139*(4), 665–682. https://doi.org/10.1037/a0020198

Kramer, A., Kümmel, J., Gollhofer, A., Armbrecht, G., Ritzmann, R., Belavy, D., Felsenberg, D., & Gruber, M. (2018). Plyometrics can preserve peak power during 2 months of physical inactivity: An rct including a one-year follow-up. *Frontiers in physiology*, *9*, 633. https://doi.org/10.3389/fphys.2018.00633

Kramer, A., Poppendieker, T., & Gruber, M. (2019). Suitability of jumps as a form of high-intensity interval training: Effect of rest duration on oxygen uptake, heart rate and blood lactate. *European journal of applied physiology*, *119*(5), 1149–1156. https://doi.org/10.1007/s00421-019-04105-w

Kruschke, J. K. (2021). Bayesian analysis reporting guidelines. *Nature human behaviour*, *5*(10), 1282–1291. https://doi.org/10.1038/s41562-021-01177-7

Kurzban, R. (2016). The sense of effort. *Current Opinion in Psychology*, *7*, 67–70. https://doi.org/10.1016/j.copsyc.2015.08.003

Kwong See, S. T., & Ryan, E. B. (1995). Cognitive mediation of adult age differences in language performance. *Psychology and aging*, *10*(3), 458–468. https://doi.org/10.1037//0882-7974.10.3.458

Laurence, N. C., Labuschagne, L. G., Lura, B. G., & Hillman, K. L. (2015). Regular exercise enhances task-based industriousness in laboratory rats. *PLOS ONE*, *10*(6), Article e0129831. https://doi.org/10.1371/journal.pone.0129831

Leonard, J. A., Lee, Y., & Schulz, L. E. (2017). Infants make more attempts to achieve a goal when they see adults persist. *Science*, *357*(6357), 1290–1294. https://doi.org/10.1126/science.aan2317

Lin, H., Westbrook, A., Fan, F., & Inzlicht, M. (2021). *An experimental manipulation increases the value of effort* [PsyArXiv]. https://doi.org/10.31234/osf.io/gnk4m

Lin, M.-H., Chou, M.-Y., Liang, C.-K., Peng, L.-N., & Chen, L.-K. (2010). Population aging and its impacts: Strategies of the health-care system in taipei. *Ageing research reviews*, *9*, 23–27. https://doi.org/10.1016/j.arr.2010.07.004

Loewenstein, G. (1999). Because it is there: The challenge of mountaineering... for utility theory. *Kyklos*, *52*(3), 315–343. https://doi.org/10.1111/j.1467-6435.1999.tb00221.x

Löllgen, H. (2004). Borg-Skala Standards der Sportmedizin. *German Journal of Sports Medicine*, *55*(11), 299–300. https://www.germanjournalsportsmedicine.com/fileadmin/content/archiv2004/heft11/299-300.pdf

Lopez-Gamundi, P., & Wardle, M. C. (2018). The cognitive effort expenditure for rewards task (c-eefrt): A novel measure of willingness to expend cognitive effort. *Psychological Assessment*, *30*(9), 1237–1248. https://doi.org/10.1037/pas0000563

Maldonato, N., Sperandeo, R., Costa, V., Cioffi, V., Cozzolino, P., Santo, R., & Scognamiglio, C. (2017). Does brain sweat pay off?: The association between the need for cognition and cognitive function among the american elderly. *J Psychol Psychother*, *7*(326), 2161–2167. https://doi.org/10.4172/2161-0487.1000326

Marcell, T. J., Hawkins, S. A., & Wiswell, R. A. (2014). Leg strength declines with advancing age despite habitual endurance exercise in active older adults. *Journal of strength and conditioning research*, *28*(2), 504–513. https://doi.org/10.1519/JSC.0b013e3182a952cc

Marques, A., Gouveira, É. R., Peralta, M., Martins, J., Venturini, J., Henriques-Neto, D., & Sarmento, H. (2020). Cardiorespiratory fitness and telomere length: A systematic review. *Journal of sports sciences*, *38*(14), 1690–1697. https://doi.org/10.1080/02640414.2020.1754739

Massar, S. A., Libedinsky, C., Weiyan, C., Huettel, S. A., & Chee, M. W. (2015). Separate and overlapping brain areas encode subjective value during delay and effort discounting. *Neuroimage*, *120*, 104–113. https://doi.org/10.1016/j.neuroimage.2015.06.080

Maxcy, J., Wicker, P., & Prinz, J. (2019). Happiness as a reward for torture: Is participation in a long-distance triathlon a rational choice? *Journal of Sports Economics*, *20*(2), 177–197. https://doi.org/10.1177/1527002518758144

Meyer, C., Dow, B., Bilney, B. E., Moore, K. J., Bingham, A. L., & Hill, K. D. (2012). Falls in older people receiving in-home informal care across victoria: Influence on care recipients and caregivers. *Australasian journal on ageing*, *31*(1), 6–12. https://doi.org/10.1111/j.1741-6612.2010.00484.x

Molanorouzi, K., Khoo, S., & Morris, T. (2014). Validating the Physical Activity and Leisure Motivation Scale (PALMS). *BMC Public Health*, *14*, Article 909. https://doi.org/10.1186/1471-2458-14-909

Mueller, C. M., & Dweck, C. S. (1998). Praise for intelligence can undermine children's motivation and performance. *Journal of personality and social psychology*, *75*(1), 33–52. https://doi.org/10.1037/0022-3514.75.1.33

Myers, J., & Bellin, D. (2000). Ramp exercise protocols for clinical and cardiopulmonary exercise testing. *Sports medicine*, *30*(1), 23–29. https://doi.org/10.2165/00007256-200030010-00003

O'Doherty, J. P., Cockburn, J., & Pauli, W. M. (2017). Learning, reward, and decision making. *Annual review of psychology*, *68*, 73–100. https://doi.org/10.1146%2Fannurev-psych-010416-044216

Palidis, D. J., & Gribble, P. L. (2020). EEG correlates of physical effort and reward processing during reinforcement learning. *Journal of Neurophysiology*, *124*(2), 610–622. https://doi.org/10.1152/jn.00370.2020

Pammolli, F., Riccaboni, M., & Magazzini, L. (2012). The sustainability of european health care systems: Beyond income and aging. *Eur J Health Econ*, *13*(5), 623–634. https://doi.org/10.1007/s10198-011-0337-8

Parraca, J. A., Adsuar, J. C., Domínguez-Muñoz, F. J., Barrios-Fernandez, S., & Tomas-Carus, P. (2022). Test-retest reliability of isokinetic strength measurements in lower limbs in elderly. *Biology*, *11*(6). https://doi.org/10.3390/biology11060802

Pereira, J. C., Neri, S. G. R., Vainshelboim, B., Gadelha, A. B., Bottaro, M., & Lima, R. M. (2019). A reference equation for normal standards for knee extensor isokinetic strength in brazilian older women. *Aging clinical and experimental research*, *31*(10), 1531–1537. https://doi.org/10.1007/s40520-018-1084-9

Pessiglione, M., Vinckier, F., Bouret, S., Daunizeau, J., & Le Bouc, R. (2018). Why not try harder? computational approach to motivation deficits in neuro-psychiatric diseases. *Brain : a journal of neurology*, *141*(3), 629–650. https://doi.org/10.1093/brain/awx278

Plassman, B. L., Langa, K. M., Fisher, G. G., Heeringa, S. G., Weir, D. R., Ofstedal, M. B., Burke, J. R., Hurd, M. D., Potter, G. G., Rodgers, W. L., Steffens, D. C., McArdle, J. J., Willis, R. J., & Wallace, R. B. (2008). Prevalence of cognitive impairment without dementia in the united states. *Annals of internal medicine*, *148*(6), 427–434. https://doi.org/10.7326/0003-4819-148-6-200803180-00005

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org/

Reid, K. F., Naumova, E. N., Carabello, R. J., Phillips, E. M., & Fielding, R. A. (2008). Lower extremity muscle mass predicts functional performance in mobility-limited elders. *The journal of nutrition, health & aging*, *12*(7), 493–498. https://doi.org/10.1007/BF02982711

Richter, M., Gendolla, G., & Wright, R. A. (2016). Three decades of research on motivational intensity theory. In A. J. Elliot (Ed.), *Advances in motivation science* (pp. 149–186, Vol. 3). Elsevier Science. https://doi.org/10.1016/bs.adms.2016.02.001

Ritz, H., Frömer, R., & Shenhav, A. (2020). Bridging motor and cognitive control: It's about time! *Trends in cognitive sciences*, *24*(1), 6–8. https://doi.org/10.1016/j.tics.2019.11.005

Robertson, R. J., & Noble, B. J. (1997). Perception of physical exertion: Methods, mediators, and applications. *Exercise and Sport Sciences Reviews*, *25*(1), 407–452. https://journals.lww.com/acsm-essr/citation/1997/00250/15_perception_of_physical_exertion_methods.17.aspx

Rosenberg, I. H. (1997). Sarcopenia: Origins and clinical relevance. *The Journal of nutrition*, *127*(5), 990–991. https://doi.org/10.1093/jn/127.5.990S

Sandra, D. A., & Otto, A. R. (2018). Cognitive capacity limitations and need for cognition differentially predict reward-induced cognitive effort expenditure. *Cognition*, *172*, 101–106. https://doi.org/10.1016/j.cognition.2017.12.004

Singh, H., Kim, D., Kim, E., Bemben, M. G., Anderson, M., Seo, D.-I., & Bemben, D. A. (2014). Jump test performance and sarcopenia status in men and women, 55 to 75 years of age. *Journal of geriatric physical therapy*, *37*(2), 76–82. https://doi.org/10.1519/JPT.0b013e3182a51b11

Singmann, H., & Kellen, D. (2020). An introduction to mixed models for experimental psychology. In D. Spieler & E. Schumacher (Eds.), *New methods in cognitive psychology* (pp. 4–31). Routledge Taylor & Francis Group. https://doi.org/10.4324/9780429318405-2

Snowden, C. P., Prentis, J., Jacques, B., Anderson, H., Manas, D., Jones, D., & Trenell, M. (2013). Cardiorespiratory fitness predicts mortality and hospital length of stay after major elective surgery in older people. *Annals of surgery*, *257*(6), 999–1004. https://doi.org/10.1097/SLA.0b013e31828dbac2

Stähler, J., Bieleke, M., & Wolff, Wanja & Schüler, Julia. (2023). *Different functions of physical effort: A scoping review of the value of physical effort in physical activity and sports.* [PsyArXiv]. https://doi.org/10.31234/osf.io/b5sv2

Stanek, J. C., & Richter, M. (2021). Energy investment and motivation: The additive impact of task demand and reward value on exerted force in hand grip tasks. *Motivation and Emotion*, *45*(2), 131–145. https://doi.org/10.1007/s11031-020-09862-2

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Sugg, M. J., & McDonald, J. E. (1994). Time course of inhibition in color-response and word-response versions of the stroop task. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(3), 647–675. https://doi.org/10.1037//0096-1523.20.3.647

Sui, X., LaMonte, M. J., Laditka, J. N., Hardin, J. W., Chase, N., Hooker, S. P., & Blair, S. N. (2007). Cardiorespiratory fitness and adiposity as mortality predictors in older adults. *JAMA*, *298*(21), 2507–2516. https://doi.org/10.1001/jama.298.21.2507

Taani, M. H., Kovach, C. R., & Buehring, B. (2017). Muscle mechanography: A novel method to measure muscle function in older adults. *Research in gerontological nursing*, *10*(1), 17–24. https://doi.org/10.3928/19404921-20161209-03

Therriault, D. J., Redifer, J. L., Lee, C. S., & Wang, Y. (2015). On cognition, need, and action: How working memory and need for cognition influence leisure activities. *Applied Cognitive Psychology*, *29*(1), 81–90. https://doi.org/10.1002/acp.3078

Tidoni, E., Borgomaneri, S., Di Pellegrino, G., & Avenanti, A. (2013). Action simulation plays a critical role in deceptive action recognition. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, *33*(2), 611–623. https://doi.org/10.1523/JNEUROSCI.2228-11.2013

Turner, W., Angdias, R., Feuerriegel, D., Chong, T. T.-J., Hester, R., & Bode, S. (2021). Perceptual decision confidence is sensitive to forgone physical effort expenditure. *Cognition*, *207*, Article e104525. https://doi.org/10.1016/j.cognition.2020.104525

van Boxtel, A., & Jessurun, M. (1993). Amplitude and bilateral coherency of facial and jaw-elevator emg activity as an index of effort during a two-choice serial reaction task. *Psychophysiology*, *30*(6), 589–604. https://doi.org/10.1111/j.1469-8986.1993.tb02085.x

van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. *Medicine and science in sports and exercise*, *29*(10), 1357–1365. https://doi.org/10.1097/00005768-199710000-00013

van der Bij, A. K., Laurant, M. G. H., & Wensing, M. (2002). Effectiveness of physical activity interventions for older adults: A review. *American Journal of Preventive Medicine*, *22*(2), 120–133. https://doi.org/10.1016/S0749-3797(01)00413-5

van Doorn, J., Ly, A., Marsman, M., & Wagenmakers, E.-J. (2020). Bayesian rank-based hypothesis testing for the rank sum test, the signed rank test, and spearman's r. *Journal of applied statistics*, *47*(16), 2984–3006. https://doi.org/10.1080/02664763.2019.1709053

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical bayesian model evaluation using leave-one-out cross-validation and waic. *Statistics and Computing*, *27*(5), 1413–1432. https://doi.org/10.1007/s11222-016-9696-4

Verghese, J., LeValley, A., Hall, C. B., Katz, M. J., Ambrose, A. F., & Lipton, R. B. (2006). Epidemiology of gait disorders in community-residing older adults. *Journal of the American Geriatrics Society*, *54*(2), 255–261. https://doi.org/10.1111/j.1532-5415.2005.00580.x

Vinckier, F., Rigoux, L., Kurniawan, I. T., Hu, C., Bourgeois-Gironde, S., Daunizeau, J., & Pessiglione, M. (2019). Sour grapes and sweet victories: How actions shape preferences. *PLOS Computational Biology*, *15*(1). https://doi.org/10.1371/journal.pcbi.1006499

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. part i: Theoretical advantages

and practical ramifications. *Psychonomic bulletin & review*, *25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Watanabe, S. (2013). A widely applicable bayesian information criterion. (14). https://www.jmlr.org/papers/volume14/watanabe13a/watanabe13a.pdf

Westbrook, A., Kester, D., & Braver, T. S. (2013). What is the subjective cost of cognitive effort? load, trait, and aging effects revealed by economic preference. *PLOS ONE*, *8*(7), Article e68210. https://doi.org/10.1371/journal.pone.0068210

Wilcoxon, F. (1992). Individual comparisons by ranking methods. In S. Kotz (Ed.), *Breakthroughs in statistics* (pp. 196–202). Springer. https://doi.org/10.1007/978-1-4612-4380-9_16

Wolff, W., Sieber, V., Bieleke, M., & Englert, C. (2021). Task duration and task order do not matter: No effect on self-control performance. *Psychological research*, *85*(1), 397–407. https://doi.org/10.1007/s00426-019-01230-1

Wolff, W., Stähler, J., & Schüler, Julia & Bieleke, Maik. (2023). *On the specifics of valuing effort: A developmental and a formalized perspective on preferences for mental and physical effort.* [PsyArXiv]. https://doi.org/10.31234/osf.io/ycvxw

Wright, P. M., Ding, S., & Li, W. (2005). Relations of perceived physical self-efficacy and motivational responses toward physical activity by urban high school students. *Perceptual and Motor Skills*, *101*(2), 651–656. https://doi.org/10.2466/pms.101.2.651-656

Yaple, Z., & Arsalidou, M. (2018). N-back working memory task: Meta-analysis of normative fmri studies with children. *Child development*, *89*(6), 2010–2022. https://doi.org/10.1111/cdev.13080

Zipf, G. (1949). *Human behavior and the principle of least effort* (Vol. 6). Addison-Wesley.

Table 1

Value of Physical Effort (VoPE) scale

Item code	Item text
VoPE01	Ich habe großen Spaß an Aktivitäten, die körperliche Anstrengung erfordern.
VoPE02	Ich bevorzuge körperlich anstrengende Aktivitäten gegenüber sportlichen Aktivitäten, die ohne größere Anstrengung bewältigt werden können.
VoPE03	Die Vorstellung, mich beim Sport körperlich anzustrengen, reizt mich.
VoPE04	Es macht mir Spaß, mich bei einer sportlichen Aktivität körperlich anzustrengen, selbst wenn es keinen Einfluss auf das Ergebnis hat.

Note. Item text provided in original German version, as it was used in the Study.

Table 2

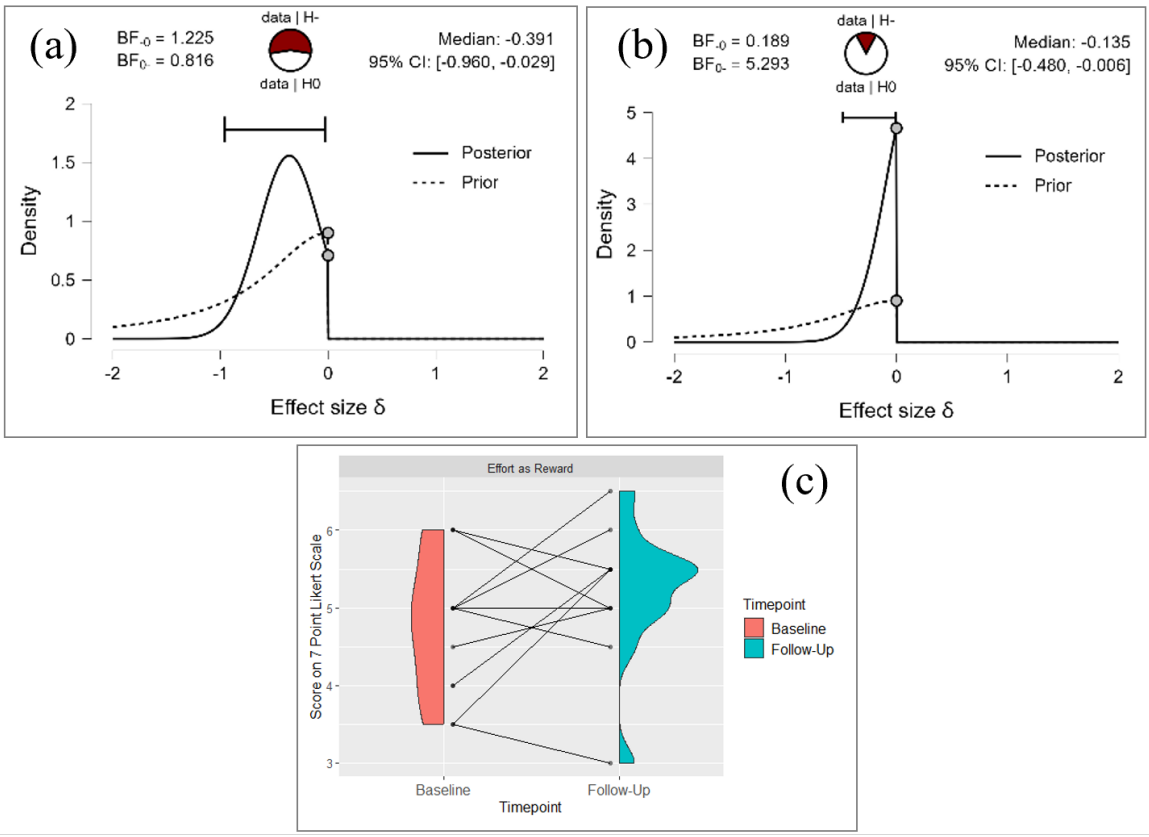
Role of Effort (RoE) scale

Itemcode	Prospective	Retrospective
RoE01	Ich freue mich darauf, mich anzustrengen, weil ich die Anstrengung genießen werde.	Im Nachhinein mag ich es, dass ich mich angestrengt habe, weil ich die physische Anstrengung wirklich genossen habe.
RoE02	Ich freue mich darauf, mich anzustrengen, weil ich Anstrengung mag.	Im Nachhinein mag ich es, dass ich mich völlig verausgaben konnte.
RoE03	Ich freue mich drauf, mich anzustrengen, da es mir hilft meine Ziele zu erreichen.	Im Nachhinein mag ich es, dass ich mich angestrengt habe, weil es mir hilft meine Ziele zu erreichen.
RoE04	Ich freue mich darauf, mich anzustrengen, weil es sich lohnen wird.	Im Nachhinein bin ich zufrieden, dass ich mich angestrengt habe, weil es sich gelohnt hat.
RoE05	Ich freue mich darauf, mich anzustrengen, weil Anstrengung meine Erfolge versüßt.	Im Nachhinein mag ich es, dass ich mich angestrengt habe, weil die Anstrengung meinen Erfolg versüßt.
RoE06	Ich freue mich darauf, mich anzustrengen, weil es mir hilft meine Erfolge zu schätzen.	Je mehr ich mich angestrengt habe, desto mehr kann ich jetzt im Nachhinein meine Erfolge feiern.

Note. Item text provided in original German version, as it was used in the Study. The *Effort as Reward* subscale is composed of the items RoE01 and RoE02. The *Effort as Instrument* subscale comprises the items RoE03 and RoE04. The *Effort as Value Added* subscale encompasses the items RoE05 and RoE06.

Figure 1

Overview Assessment of Intervention Effects for Value of Effort scales



Note. (a) EaR & (b) VoPE: Results of a one-sided Bayesian signed rank test for the parameter δ. The probability wheel on top visualizes the evidence that the data provide for the two rival hypotheses. The dashed line indicates the Cauchy prior with scale $r = 1/\sqrt{2}$. The two grey dots indicate the prior and posterior ordinate at the point under test in this case $\delta = 0$. The ratio of the ordinates gives the Bayes factor. (c) EaR: Raincloud Plot illustrating the distribution of EaR scores at Baseline and Follow-Up. Density plots provide a visual representation of the data distribution. Individual trajectories (black lines) depict the change in EaR scores for each participant across timepoints.

Table 3

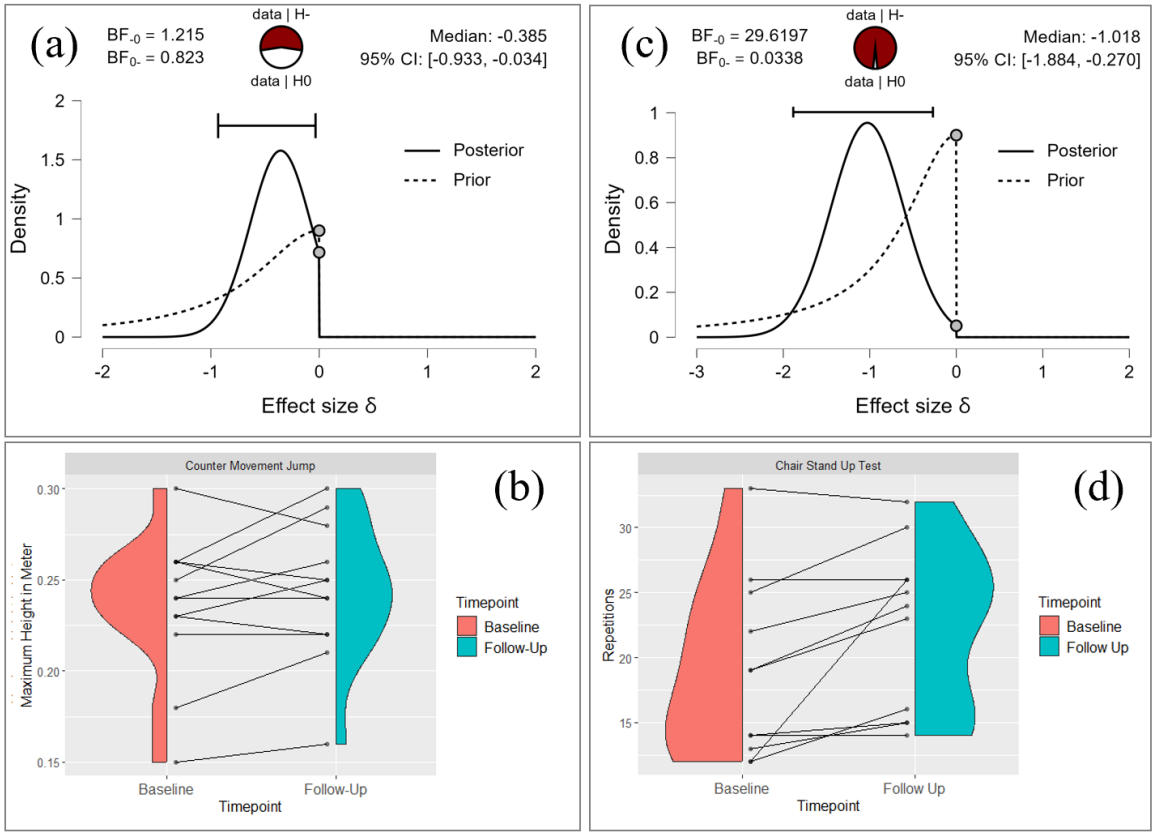
Bayesian Wilcoxon Signed-Rank Test for Physical Abilities

Baseline		Follow-Up	BF_{-0}	W	Rhat
Base CMJ	-	Post CMJ	1.215	14.500	1.001
Base R-KneeExt	-	Post R-KneeExt	0.817	27.000	1.001
Base L-KneeExt	-	Post L-KneeExt	0.182	52.000	1.000
Base R-KneeFlx	-	Post R-KneeFlx	0.393	37.000	1.000
Base L-KneeFlx	-	Post L-KneeFlx	0.177	52.000	1.000
Base VO2max	-	Post VO2max	0.287	37.000	1.001
Base CST	-	Post CST	29.620	1.500	1.008

Note. Bayesian Wilcoxon Signed-Rank Test results for all physical fitness measures at Baseline and Follow-Up. The Bayes Factor (BF_{-0}) indicates the evidence against the null hypothesis. W represents the test statistic, and Rhat is the potential scale reduction factor for assessing convergence in the Bayesian analysis. For all tests, the alternative hypothesis specifies that Baseline is less than Follow-Up.

Figure 2

Overview Assessment of Intervention Effects for Physical Abilities



Note. (a) CMJ & (b) CST: Results of a one-sided Bayesian signed rank test for the parameter δ. (c) CMJ & (d) CST: Raincloud Plot illustrating the distribution of maximal jump height/ repetitions at Baseline and Follow-Up. See Figure 1 for a detailed description.

Table 4

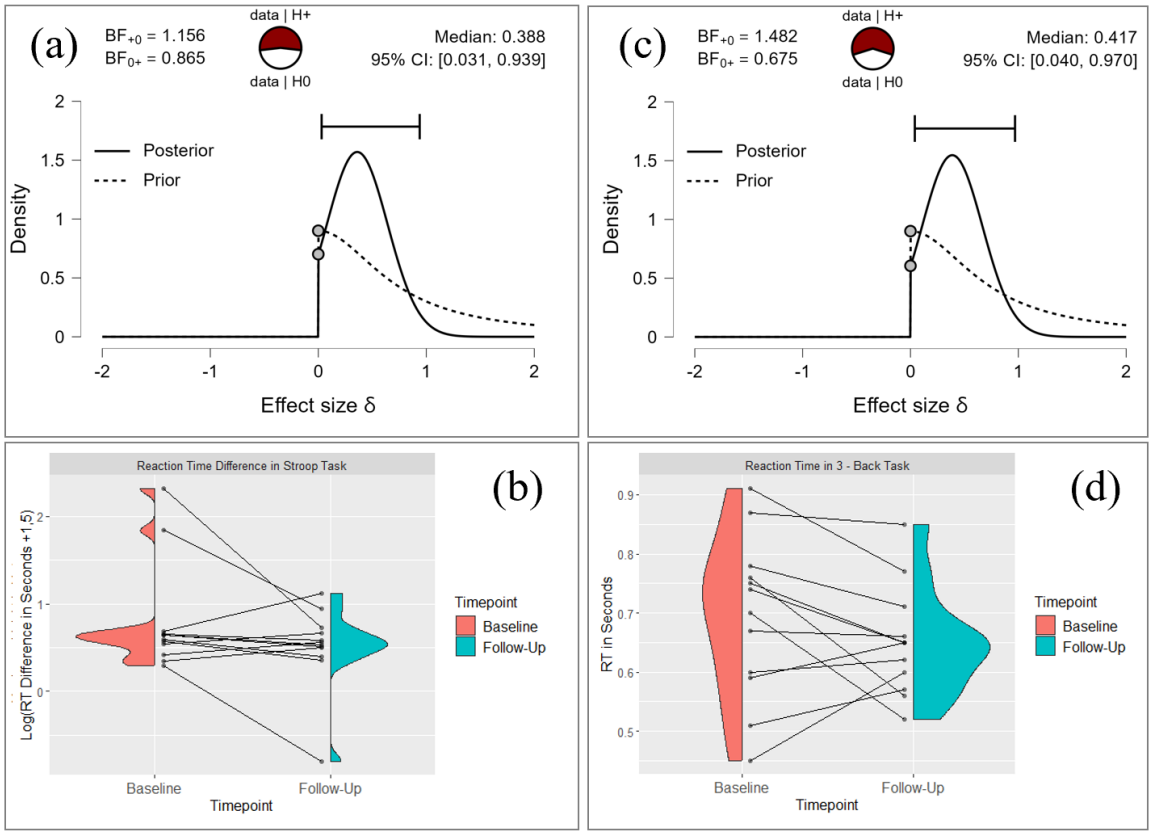
Bayesian Wilcoxon Signed-Rank Test for Success Rates of Cognitive Tasks

Baseline		Follow-Up	BF_{-0}	W	Rhat
Base Stroop Suc	-	Post Stroop Suc	0.374	28.000	1.000
Base 2-Back Suc	-	Post 2-Back Suc	0.289	35.000	1.000
Base 3-Back Suc	-	Post 3-Back Suc	0.103	56.000	1.008

Note. Bayesian Wilcoxon Signed-Rank Test results for success rates of cognitive tasks at Baseline and Follow-Up. See Table 3 for a detailed description.

Figure 3

Overview Assessment of Intervention Effects for Cognitive Abilities



Note. (a) Stroop & (b) 3-Back: Results of a one-sided Bayesian signed rank test for the parameter δ. (c) Stroop & (d) 3-Back: Raincloud Plot illustrating the distribution of Log (+1,5) transformed RT Difference/ RT at Baseline and Follow-Up. See Figure 1 for a detailed description.

Table 5

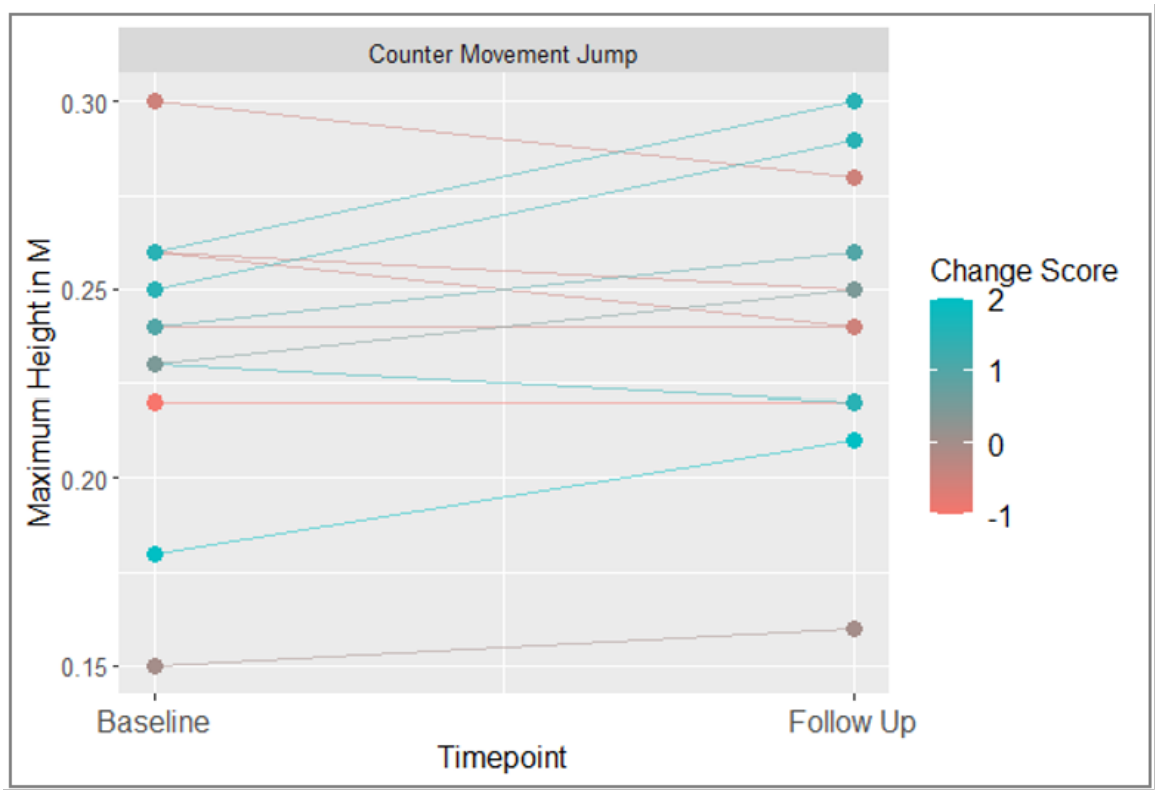
Fixed Effects Estimates for Counter Movement Jump regression model

			95% CI			
Term	Estimate	SE	Lower	Upper	R-hat	ESS
Intercept	0.240	0.012	0.217	0.263	1.000	1708.817
Timepoint (1)	0.001	0.005	−0.008	0.011	1.000	3751.123
Change Scores	-7.931×10^{-4}	0.011	−0.022	0.021	1.001	1484.833
Timepoint (1) * Change Scores	0.011	0.004	0.002	0.019	1.000	3982.091

Note. Estimates represent the effect of each term on the response variable, with standard errors (SE) and 95% confidence intervals (CI) provided. R-hat is the potential scale reduction factor, and ESS is the effective sample size, indicating convergence in the Bayesian analysis.

Figure 4

Trajectory Plot Counter Movement Jump



Note. Trajectory Plot illustrating the distribution of maximum jump height at Baseline and Follow-Up. Individual trajectories depict the change in performance for each participant across timepoints.The color gradient reflects the Change Scores of EaR.

Table 6

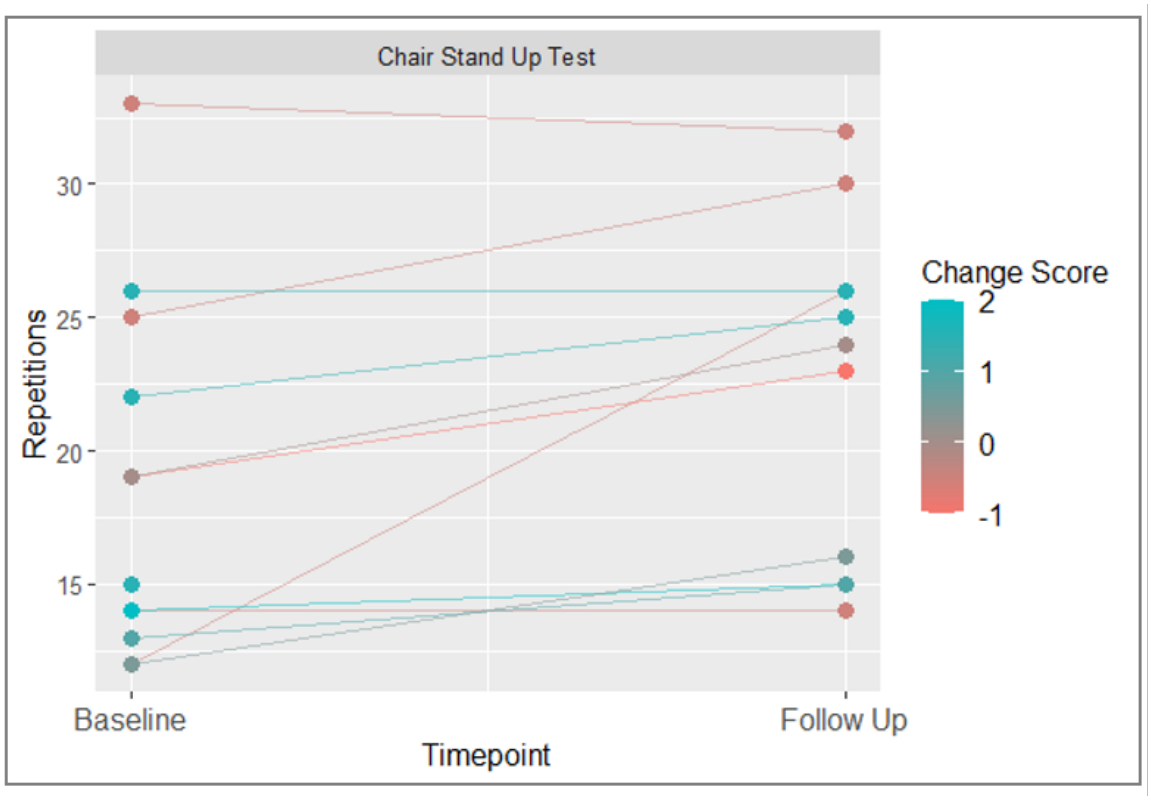
Fixed Effects Estimates for the Chair Stand Up Test regression model

			95% CI			
Term	Estimate	SE	Lower	Upper	R-hat	ESS
Intercept	21.081	1.934	17.215	24.893	1.000	2045.567
Timepoint (1)	2.743	1.178	0.417	5.134	1.001	5138.272
Change Scores	−1.605	1.862	−5.295	2.019	1.003	1945.062
Timepoint (1) * Change Scores	−0.900	1.116	−3.158	1.329	1.000	5725.112

Note. See Table 5 for a detailed description.

Figure 5

Trajectory Plot Chair Stand Up Test



Note. Trajectory Plot illustrating the distribution of number of repetitions in the CST at Baseline and Follow-Up. See Figure 4 for a detailed description.

Table 7

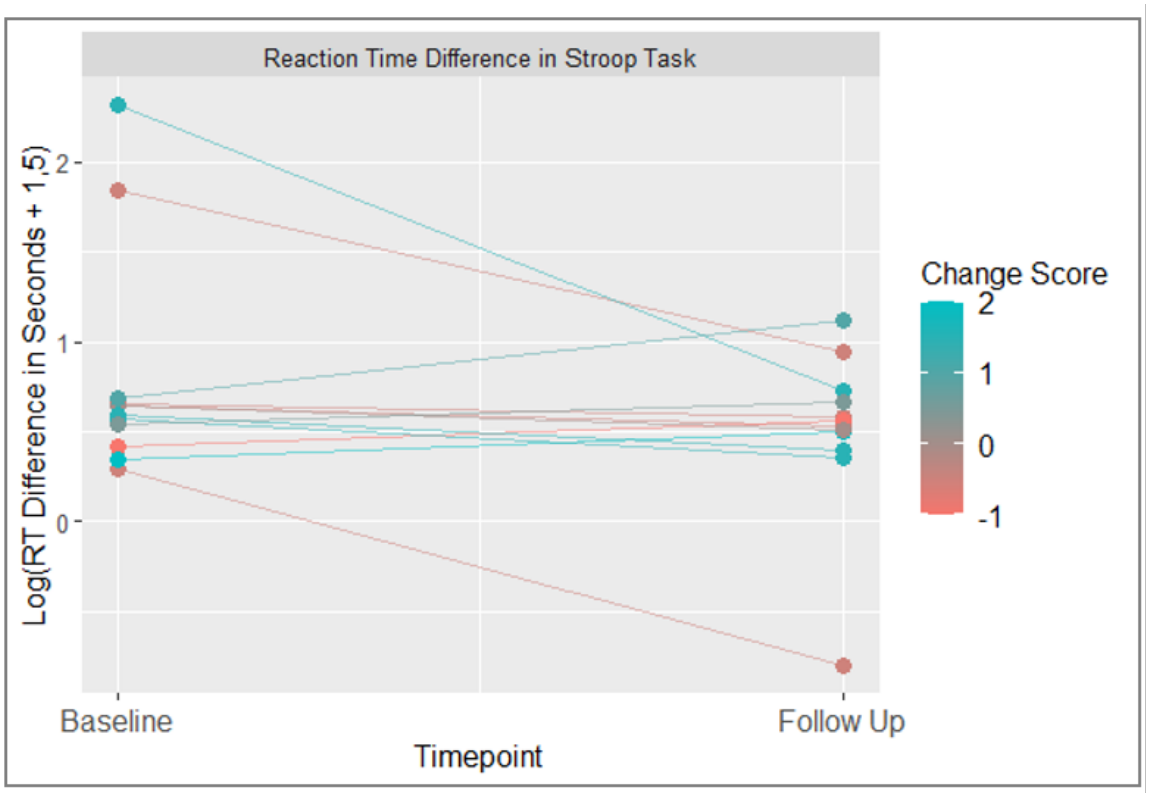
Fixed Effects Estimates for the RT Differences Stroop regression model

			95% CI			
Term	Estimate	SE	Lower	Upper	R-hat	ESS
Intercept	0.693	0.539	−0.402	1.755	1.001	3387.272
Timepoint (1)	−0.615	0.591	−1.793	0.583	1.000	5737.915
Change Scores	0.237	0.491	−0.745	1.203	1.000	4173.658
Timepoint (1) * Change Scores	−0.240	0.545	−1.325	0.848	1.000	5521.988

Note. See Table 5 for a detailed description.

Figure 6

Trajectory Plot RT Difference in Stroop Task



Note. Trajectory Plot illustrating the distribution of Log (+1,5) transformed RT Differences in the Stroop task at Baseline and Follow-Up. See Figure 4 for a detailed description.

Table 8

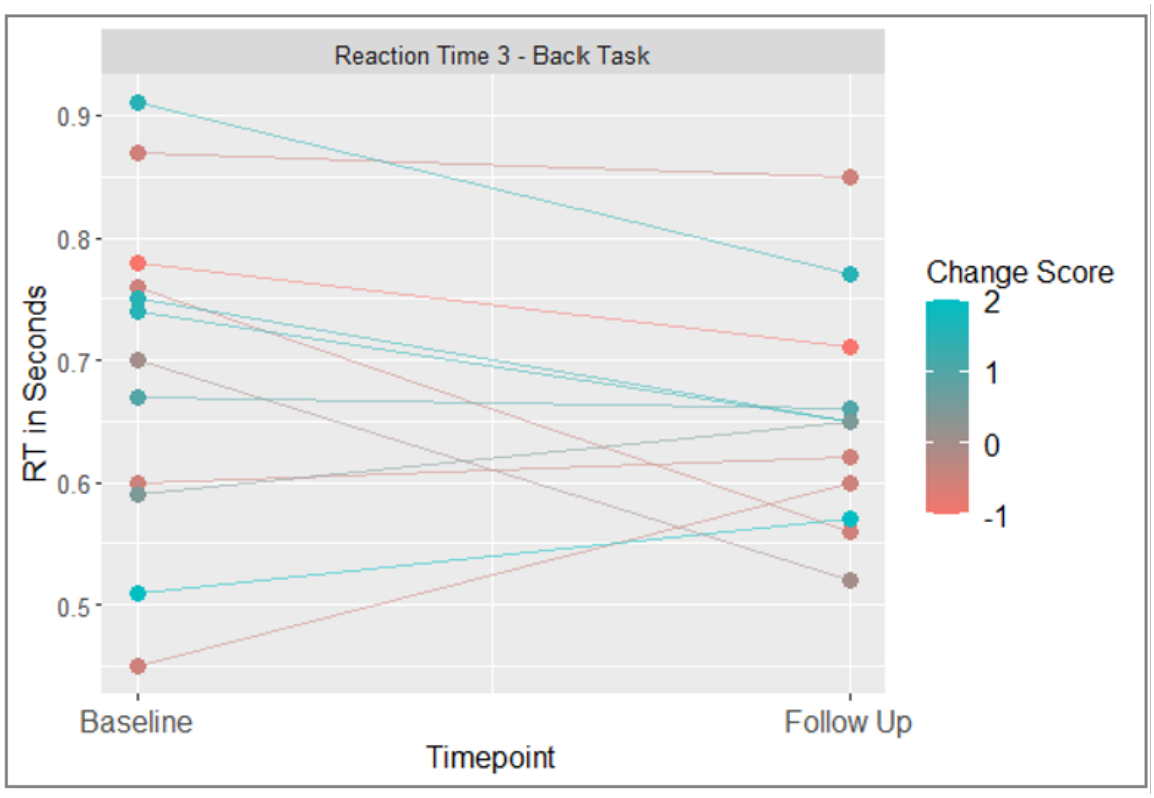
Fixed Effects Estimates for the RT 3-Back regression model

			95% CI			
Term	Estimate	SE	Lower	Upper	R-hat	ESS
Intercept	0.673	0.036	0.603	0.745	1.001	3089.254
Timepoint (1)	−0.029	0.029	−0.088	0.028	1.000	6143.939
Change Scores	−0.002	0.033	−0.068	0.063	1.000	3114.780
Timepoint (1) * Change Scores	−0.003	0.027	−0.057	0.049	1.000	6063.035

Note. See Table 5 for a detailed description.

Figure 7

Trajectory Plot RT 3-Back Task



Note. Trajectory Plot illustrating the distribution of reaction times in the 3-Back task at Baseline and Follow-Up. See Figure 4 for a detailed description.

Appendix A

Exercises in the Jump HIIT Intervention

Exercise	Description
Counter Movement Jump	Jumped squats, downward movement serves as a lunge for subsequent jump, land, and directly next jump.
Tappings	Quick sprint on the spot, quickly alternating feet off the ground a few centimeters.
Alternating jumps	Similar as lunges but jumped foot change.
Small dropout steps	Arms on hips or swing along, step forward with one leg, push off and return to starting position, then step forward with the other leg.
Climbing movement	Extend one arm upward, pull diagonal knee upward: alternate arms and legs.
Quick squats	Stand hip-width apart, support your arms on your hips, perform vigorously and do not go too low.
Skippings	Similar as running on the spot, while pulling the knees further up; swinging arms along with them.
Running on the spot	Jogging, arms swinging along.

Note. This Table is adapted from Campoverde (2023).

Appendix B

Trainingsprotokoll von: _____

Submaximale HR (70 – 80%): _____

Maximale HR (85 – 95%): _____

Woche 1 – Vorbereitung

	Laufen	Skippings	Kniebeugen	Steigebewegung	Ausfallschritte
Tag 1					
Tag 2					
Tag 3					

Woche 2 – Submaximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 3 – Submaximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 4 – Submaximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 5 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 6 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 7 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 8 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 9 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 10 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 11 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					

Woche 12 – Maximal

	Laufen	Skippings	CM-Jumps	Tappings	Wechselsprünge
Tag 1					
Tag 2					
Tag 3					