

Physical Activity Interventions: Effects on Well-Being Outcomes in Older Adults

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Abstract:

A corpus of literature has documented the benefits of physical activity to well-being and quality of life in older adults. However, this relationship has frequently been studied in the context of health-related quality of life (HRQL), as opposed to global quality of life, and in clinical populations. While meta-analyses in this area provide strong evidence of a positive effect of physical activity on HRQL in these populations, systematic evidence is lacking in relation to well-being and global quality of life in healthy older adults. A small number of randomized controlled trials suggest physical activity benefits global quality of life; however, additional research using the global conceptualization of well-being is needed to confirm these findings. There is strong evidence, on the other hand, of a positive influence of physical activity on the proposed antecedents of HRQL and global well-being, including self-related function, or psychological states (i.e., depression, anxiety, self-esteem, positive affect, self-efficacy), and cognitive function (e.g., executive function, working memory) in older adults. Despite this, less is known about the: (1) modes and doses of physical activity that most effectively improve self-related function, cognitive function, HRQL, and well-being; (2) mechanisms of change in well-being outcomes due to increased physical activity; and (3) mediating roles of self-related function, cognitive function, and HRQL in the broader relationship between physical activity and well-being. In this chapter, we present current evidence of physical activity's effects on well-being and its correlates, HRQL, self-related function, and cognitive function. We also highlight limitations in this evidence base and provide recommendations for future research.

Keywords: Physical activity, subjective well-being, quality of life, older adults

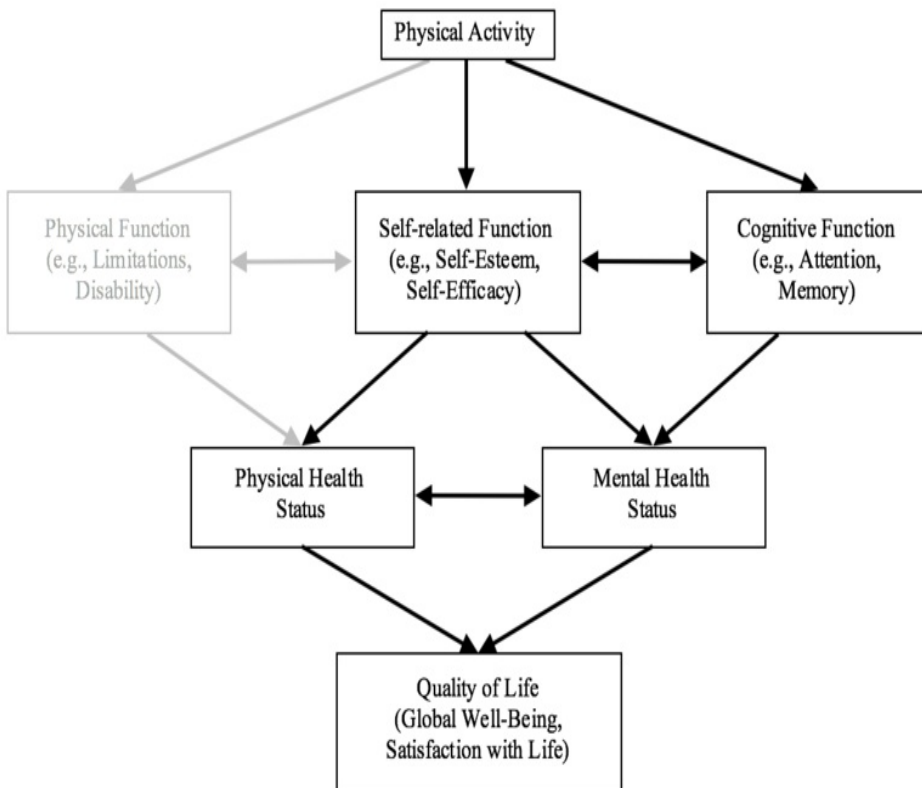
There has been a rapid shift in the demographic landscape of the United States in the last few decades, a result of adults now living longer than ever before (Vincent & Velkoff, 2010). However, older adulthood is a period often fraught with the onset of comorbid conditions and disability, which can lead to impaired well-being and quality of life (QoL; Ward, Schiller, & Goodman, 2012). Defined as an affective cognitive judgment of one's satisfaction with life, QoL is a global construct often used interchangeably with subjective well-being and considered a significant predictor of long-term survival (Diener, Emmons, Larsen, & Griffin, 1985). Thus, it has become an important priority for researchers and clinicians to identify low-cost, effective methods of maintaining older adults' well-being and QoL and to protect against age-related health decline.

Physical activity may be an effective vehicle for improving well-being and QoL with increased age. In this chapter we focus on physical activity's effects on the psychological (e.g., satisfaction with life, anxiety, esteem, affect, cognition) rather than the physical (e.g., functional performance, activities of daily living) components of well-being. We also focus on QoL as a global judgement of well-being. However, the physical activity literature has given limited attention to QoL following this definition. Rather, this literature has focused primarily on health status, or health-related quality of life (HRQL), while operationalizing it as QoL (Chou, Hwang, & Wu, 2012; Gillison, Skevington, Sato, Standage, & Evangelidou, 2009; Motl & Gosney, 2008).

HRQL is a construct derived from behavioral medicine and biomedical science and is comprised of physical and mental health domains (Ware Jr. & Sherbourne, 1992). It is distinct from well-being and QoL and considered by some researchers to be a proximal outcome along the pathway between physical activity and well-being. For example, McAuley and Morris (2007) proposed that physical activity has a direct impact on self-related function (self-esteem, self-efficacy, affect), cognitive function, and physical function, which impact HRQL (physical and mental health domains). In turn, improved HRQL directly influences global QoL (Figure 1). As this follows theoretical suppositions of subjective well-being (Diener, 1984; Rejeski & Mihalko, 2001), our discussion herein is guided by this framework.

A compelling body of evidence has demonstrated the effectiveness of physical activity interventions for improving health status, reducing negative psychological states (e.g., depression, anxiety), and increasing positive psychological states (e.g., self-esteem; Arent, Landers, & Etnier, 2000; Barbour, Edenfield, & Blumenthal, 2007; Clarke et al., 2005; Ensari, Greenlee, Motl, & Petruzzello, 2015). Likewise, a number of studies have identified the efficacy of physical activity interventions for improving cognitive health (Northey et al., 2017; Smith et al., 2010), a key component of successful aging and well-being in older adults (Diener, 1984; Fiocco & Yaffe, 2010; Lehnert, Sudeck, & Conzelmann, et al., 2012). Despite this, the final path to well-being and global QoL has rarely been tested in accordance with McAuley and Morris’s (2007; see Figure 1) hypothesized model. In this chapter we present current evidence relative to subjective well-being in the context of global QoL and HRQL, self-related function (i.e., psychological states), and cognitive function; identify strengths and shortcomings (relative to design in particular, theoretical underpinnings, measurement, mode and dose of activity, potential mechanisms and moderators); and make recommendations for future research directions.

Figure 1. A conceptual model of the physical activity and quality-of-life relationship*
 *Adapted from McAuley and Morris (2007)



Note: Physical function is presented in gray as it is included in the original model proposed by McAuley and Morris (2007), but is not the focus of this book chapter.

Global Well-Being

A small number of randomized controlled trials (RCTs) have shown that aerobic and non-aerobic modes of physical activity may improve subjective well-being (Awick et al., 2015, 2017b; Li et al., 2001). Unfortunately, this limited literature, in addition to inconsistent conceptualizations of well-being, make it difficult to synthesize findings across studies and conclude whether physical activity interventions improve well-being in older adults (Rejeski & Mihalko, 2001). As such, meta-analytic studies and systematic reviews examining older adults' physical activity and well-being from the global perspective are scarce in the literature. A further limitation of this evidence is that it has focused primarily on clinical populations, thus making generalizations to healthy older adults difficult. In this section we discuss: the effects of physical activity on HRQL; the small body of evidence focusing on global QoL; and future directions to better understand the influence of physical activity on these constructs in older adults.

Physical Activity and Health-related Quality of Life

As noted above, physical activity and HRQL have largely been studied from the perspective of clinical populations (Chou et al., 2012; Ferrer, Huedo-Medina, Johnson, Ryan, & Pescatello, 2011; Motl & Gosney, 2008). To the best of our knowledge, only one meta-analysis has focused on healthy populations and included adults aged 18 to 65+ years (Gillison et al., 2009). Motl and Gosney (2008) observed a small to moderate effect ($d = .34$) of short-term (<3 months), aerobic physical activity interventions on HRQL in individuals with multiple sclerosis (MS). Longer interventions and non-aerobic (i.e., yoga, resistance training) or combined programs did not yield the same benefits. Ferrer and colleagues (2011) also observed increases in cancer survivors' HRQL after participation in aerobic physical activity interventions; however, they found that studies of longer duration (>6 months) had a greater influence on HRQL, and these improvements were maintained ~4.5 months after the interventions ended.

Gillison and colleagues (2009) also found that short-term (3-6 months) physical activity interventions yielded significant, albeit small, improvements in the physical and mental domains of HRQL in healthy adults, ($d = 0.22, 0.21$, respectively). Interestingly, the mental domain of HRQL improved more after engaging in light intensity activity, whereas the physical domain improved only with moderate intensity activity (Gillison et al., 2009). This suggests the HRQL domains may be differentially impacted by physical activity intensities. This may be due in part to recruitment of healthy, yet unfit and inactive individuals who may have perceived light physical activity as more achievable and enjoyable, thereby improving the mental HRQL domain. While results from these meta-analyses suggest aerobic activity may be a viable mode for increasing HRQL in clinical and healthy populations, more studies are warranted.

The implications of these findings are restricted by a number of limitations. First, the focus on clinical populations and HRQL limits broad understanding of physical activity's effects on well-being in older adults. For example, in the meta-analysis in MS patients by Motl and Gosney (2008), the effect of physical activity on HRQL was statistically significant when using MS-specific HRQL measures, but non-significant when using broad measures such as the Medical Outcomes Study 36-item Short Form Survey (Motl & Gosney, 2008; Ware Jr. & Sherbourne, 1992). Moreover, the effect of physical activity on HRQL and well-being may be greater in clinical populations when compared with the general older adult population (Ferrer et al., 2011; Gillison et al., 2009). It is also possible that physical activity impacts clinical populations differently or may work along different underlying pathways. Similarly, HRQL is a proximal outcome of physical activity and thought to be more of an indicator of health status (Stewart & King, 1991). As such, more research with a focus on global QoL and well-being in clinical and general older adult populations may enable us to better quantify the effects of physical activity on subjective well-being.

Additionally, more details are needed on the intervention characteristics, such as mode, frequency, intensity, duration, and settings that are most effective for improving HRQL in older adults. The extant literature suggests shorter interventions and light intensity exercise may have larger effects on HRQL, but further research should be conducted to confirm these findings. Finally, HRQL domains may be differentially sensitive to the effects of physical activity (Chou et al., 2012; Gillison et al., 2009); therefore, research is needed to explain relationships among physical activity, physical and mental HRQL, and global QoL. A few studies in the older adult literature have aimed to reduce these knowledge gaps (see below); however, more work in this area is warranted.

Physical Activity and Global Quality of Life

A smaller, yet important body of literature has assessed the impact of physical activity on global QoL and well-being, using satisfaction with life as the proxy measure. For example, Awick and colleagues (2015) examined the effects of a walking intervention compared with a stretching/toning control intervention on satisfaction with life in low-active older adults at mid-intervention (6 months) and post-intervention (12 months). Both groups reported increases in life satisfaction at 6 months; however, the walking intervention continued to improve their life satisfaction throughout the 12 months, while the

stretching/toning group declined from months 6 to 12. Li and colleagues (2001) also observed a large effect ($d = .93$) on satisfaction with life in older adults who participated in a 6-month Tai Chi intervention compared to a no-treatment control group. Findings from these studies suggest aerobic and non-aerobic (stretching, toning, alternative exercise) exercise modalities have the capacity to improve subjective well-being in older adults, but aerobic activity may have a greater, long-lasting impact. Notably, participants of both interventions were generally healthy, suggesting the benefits of physical activity programs to well-being are not restricted to clinical populations or those with compromised HRQL or QoL.

Contrary to these findings, a meta-analysis that included satisfaction with life as an outcome of QoL reported no significant differences between physical activity groups and controls (Netz, Wu, Becker, & Tenenbaum, 2005). However, this meta-analysis had several limitations to be considered. For example, a table of study characteristics was not included, methodological quality was not evaluated, and specific measures used to assess global QoL were not reported in the meta-analysis, thus making interpretation of these findings difficult.

In keeping with the theoretical conceptualization of well-being as a global, distal outcome of physical activity (Figure 1), researchers have also tested the indirect effect of physical activity. For instance, in a prospective study of older women, McAuley and colleagues (2008) found that changes in physical activity were associated with changes in self-efficacy, which was in turn significantly associated with changes in HRQL. Changes in mental health status were then significantly associated with changes in satisfaction with life. The authors suggested that lack of findings in the physical health domain may be due to the observational design, as individuals are more likely to improve physical function (e.g., strength, flexibility) within the context of an intervention. A cross-sectional study by Mudrak and colleagues (2016) also found that increased participation in physical activity was associated with greater self-efficacy in 546 older Czech adults. Greater self-efficacy was associated with better HRQL, and HRQL was associated with higher satisfaction with life. Together, these findings provide support for proposed relationships between physical activity and global QoL. However, as our interpretations are limited by the study designs (prospective and cross-sectional), further research in the context of an RCT is needed to test the directionality and causality of the relationships. Despite this, a robust literature provides strong evidence in support of physical activity's benefits to proximal outcomes associated with well-being, such as HRQL, self-related function, and cognitive function.

Self-related Function

A considerable body of literature has highlighted the positive influence of physical activity interventions on psychological outcomes in older adults, specifically for reducing negative symptomology (i.e., depression, anxiety) and improving positive psychological states (i.e., esteem, positive affect; Arent et al., 2000; Barbour et al., 2007; Clarke et al., 2005; Ensari et al., 2015). These effects have remained relatively consistent across levels of exercise supervision (e.g., center- v. home-based) and mode (e.g., aerobic v. non-aerobic). However, the mechanisms underlying physical activity's influence on these factors, as well as their concurrent influence on the larger relationship between physical activity and subjective well-being are still unclear. In this section, we present evidence of the influence of physical activity on negative and positive psychological states in older adults, including findings related to dose-response and mode of exercise.

Negative Psychological States

Negative psychological states are important concerns for older adults and have been consistently associated with increased risk of morbidity and mortality when left untreated (Blake, Mo, Malik, & Thomas, 2009). Although McAuley and Morris (2007) defined self-related function in terms of positive psychological states only, negative affective outcomes are an important component of subjective well-being (Diener, 1984) and a robust literature provides evidence in support of physical activity interventions for improving negative psychological symptoms (Arent et al., 2000; Barbour & Blumenthal, 2005; Blake et al., 2009; Herring et al., 2010; Penedo & Dahn, 2005; Rosenbaum et al., 2011). Barbour and Blumenthal (2005) reported physical activity to be more effective for reducing depressive symptoms when compared with wait-list and social contact controls and antidepressant medications. Conn (2010) corroborated these findings in a meta-analysis and noted that both supervised and unsupervised physical activity interventions in older adults were comparable in reducing depressive symptoms. The magnitude of physical activity's effect on depression across studies was moderate ($ds \sim 0.38$).

Exercise interventions have also been shown to reduce anxiety levels in older adults (Arent et al., 2000; Herring et al., 2010; Penedo & Dahn, 2005). In an update to a previous comprehensive review of the anxiety-reducing influence of acute and regular exercise (Petruzzello, Landers, & Hatfield, 1991), Ensari and colleagues (2015) confirmed the small, but significant, beneficial effect of acute bouts of physical

activity on anxiety. Indeed, some of the most robust effects of physical activity on psychological well-being in older adults have been on anxiety symptoms (Netz et al., 2005). While more recent evidence examining the influence of regular physical activity on anxiety is needed, the extant literature overall unequivocally supports a beneficial effect of physical activity on negative affect in older adults. However, as the effects are not entirely uniform, there are several considerations for maximizing the benefits of physical activity in future trials. Specifically, further exploration of physical activity dose, mode, and underlying mechanisms is warranted. This is further discussed later in the chapter in the Future Directions section.

Positive Psychological States

Other important determinants of health in old age are factors associated with positive psychological states, such as self-esteem, self-efficacy, and positive affect. Self-esteem, one's affective evaluation of his/her worth, and self-efficacy, one's situation-specific self-confidence, are two constructs that have been associated with successful aging (Orth, Robins, & Roberts, 2008; Orth, Robins, & Widaman, 2012; Rejeski & Mihalko, 2001). Although meta-analytic reviews have consistently revealed significant, but small improvements in self-esteem, self-efficacy, and positive affect with exercise training ($d_s = .16-.57$; standardized mean difference [SMD] = .50; (Ashford, Edmunds, & French, 2010; Ekland, Heian, Hagen, & Coren, 2005; Reed & Buck, 2009; Spence, McGannon, & Poon, 2005; Wiese, Kuykendall, & Tay, in press), most have failed to include individuals over the age of 60. As there is a paucity of systematic evidence focused on positive psychological states in older adults specifically, we focus here instead on exemplar RCTs. For example, older adults randomized to a 12-month walking group versus flexibility-toning-balance control group reported similar improvements in physical self-worth, a domain of self-esteem (Gothe et al., 2011). Similarly, Awick and colleagues (2017a) found that a home-based, DVD-delivered flexibility/toning/balance exercise program helped older adults improve and maintain their physical self-worth immediately post-intervention (6 months) and after a one year, no-contact follow-up period.

There is a demonstrative body of evidence highlighting the reciprocal relationship between physical activity and self-efficacy in older adults, such that self-efficacy acts as both a determinant and outcome of physical activity behavior (Anderson, Winett, Wojcik, & Williams, 2010; Bandura, 1997; Chase, 2013; McAuley & Blissmer, 2000). As such, self-efficacy has become widely recognized as an important intervention target in numerous physical activity studies in older adults (Amireault, Godin, & Vézina-Im, 2013; Heath et al., 2012). In a meta-analysis by Ashford et al. (2010), the largest effects for increased self-efficacy were evidenced in physical activity interventions that included a greater emphasis on vicarious experience and performance feedback, making these important considerations for future interventions. Elavsky and colleagues (2005) reported that, among individuals randomized to a 6-month exercise intervention, those who remained more physically active at one-year follow-up reported higher levels of self-efficacy, self-esteem, and positive affect. It should be noted that these effects were maintained at 5-year follow-up for self-esteem and positive affect, further suggesting that physical activity interventions can provide long-lasting improvements in positive psychological states responses.

Cognitive Health

Cognition and brain health have increasingly been recognized as important factors of successful aging and may be considered significant components of older adults' subjective well-being (Fiocco & Yaffe, 2010; Kramer & Erickson, 2007; Lehnert et al., 2012; McAuley & Morris, 2007; Rowe & Kahn, 1997). A small number of studies have linked cognition with well-being (Gerstorf, Lövdén, Röcke, Smith, & Lindenberger, 2007), and several have connected it with well-being correlates, including depression, anxiety, self-esteem, and self-efficacy (Agroskin, Klackl, Jonas, Downs, & Caspi, 2014; Birch et al., 2016; McAuley et al., 2011). A large body of research has provided evidence in support of regular physical activity for slowing cognitive decline, improving brain health and cognitive function with advancing age, and reducing risk of dementia and Alzheimer's disease (Bherer, Erickson, & Liu-Ambrose, 2013; Blondell, Hammersley-Mather, & Veerman, 2014; Colcombe & Kramer, 2003; Smith et al., 2010). While a smaller number of studies have questioned the overall effectiveness of physical activity for preserving cognitive function in older adults (Kirk-Sanchez & McGough, 2013; Young, Angevaren, Rusted, & Tabet, 2015), physical activity is generally accepted as protective against age-related cognitive decline. It is less clear which dimensions of activity (i.e., frequency, intensity, duration, mode) most effectively ameliorate cognitive decline, mechanisms by which physical activity influences cognitive function, and the effects of cognitive function on well-being. In this section, we review evidence of the effects of physical activity on cognitive function in older adults and emphasize important areas of further scientific investigation.

A number of meta-analyses and systematic reviews have attempted to quantify the effects of physical activity on cognitive function in older adults, with most focusing on aerobic exercise. In an early meta-analysis of 18 randomized aerobic exercise trials, Colcombe and Kramer (2003) reported that aerobic

exercise was moderately effective for improving cognitive function in older adults (Hedge's $g = 0.48$), and these benefits were greatest for executive control processes (e.g., cognitive flexibility, inhibition, planning; $g = 0.68$). More recent meta-analyses and reviews have corroborated these findings, but suggest aerobic exercise's effects on cognitive function may be somewhat smaller. Smith and colleagues (2010) found, across 29 aerobic interventions in adults aged 18 years and older, that aerobic exercise consistently led to modest improvements in attention and processing speed ($g = 0.16$), executive function ($g = 0.12$), and memory ($g = 0.13$). In the most recent meta-analysis, aerobic exercise ($k=18$) in adults aged 50 years and older was associated with improvements in cognition compared with controls (SMD = 0.24; Northey et al., 2017). Like Smith et al. (2010), the effects were similar across cognitive domains (i.e., attention, executive function, memory, working memory; SMDs = 0.27-0.36; Northey et al., 2017). Despite these positive findings, the most recent Cochrane review reported no evidence of an association among aerobic exercise (compared to non-aerobic exercise or no intervention), cardiorespiratory fitness, and cognitive function in cognitively intact older adults aged 55 years and older (Young et al., 2015). This is also in contrast to previous studies suggesting improvements in cardiorespiratory fitness brought about by increases in aerobic physical activity may at least partially explain enhancements in cognitive function among older adults (Erickson et al., 2011; McAuley, Kramer, & Colcombe, 2004).

It is important to note the limitations in this evidence base, particularly in relation to study design, risk of bias, and poor reporting of methods (Colcombe & Kramer, 2003; Fiocco & Yaffe, 2010; Northey et al., 2017; Young et al., 2015). In the Cochrane review, Young and colleagues (2015) acknowledged a preponderance of cross-sectional and observational studies, unclear randomization schemes in RCTs, lack of participant and trainer blinding to exercise protocols, per-protocol analytic procedures, limited number of published protocols, poor reporting of attrition, no assessment of contamination bias, and limited discussion of ceiling effects. These factors may have contributed to the small or null effects observed across studies.

Although most studies have provided evidence of a positive main effect of aerobic exercise on cognitive function, results of moderator analyses have been mixed. For example, Colcombe and Kramer (2003) observed varied relationships with cognitive performance across dimensions of fitness including trial length and bout duration. Long-term training programs (6+ months; $g = 0.67$) and bout durations of 31-45 minutes ($g = 0.61$) were associated with better cognitive performance. Contrary to this, Smith et al. (2010) and Northey et al. (2017) observed similar cognitive effects across trials of varying lengths (Smith et al. (2010): range 8-72 weeks; Northey et al. (2017) categorized: 4-12 weeks, 13-26 weeks, >26 weeks). Additionally, the effect of exercise bout duration on cognitive function followed a quadratic trend in which only medium duration exercise bouts (i.e., >45 to ≤ 60 minutes) led to improvements in cognitive functioning (Northey et al., 2017).

A growing body of evidence also suggests the cognitive benefits of exercise are not restricted to aerobic exercise. Combined aerobic exercise + strength training programs, while comprising only a small number of studies examined by Colcombe and Kramer (2003), had greater effects on cognitive function when compared with aerobic exercise only ($g = 0.59$ v. 0.41). The cognitive effects observed by Smith and colleagues (2010) were evident regardless of training received (i.e., aerobic v. aerobic + strength). Likewise, Northey and colleagues (2017) observed similar improvements in cognitive function across 41 exercise interventions of different modes (aerobic exercise [SMD = 0.24], resistance training [SMD = 0.29], combined training [SMD = 0.33], tai chi [SMD = 0.52]). Although much additional work is needed, the evidence to date indicates cognition should be fundamental to the discussion of physical activity's effects on subjective well-being in older adults.

Future Directions

The extant literature suggests further research in a number of areas in order to better understand the roles of physical activity and proximal outcomes, such as psychological health, cognitive health, and HRQL, in improving subjective well-being in older adults. Research areas of particular interest include examination of (a) alternate modes of physical activity; (b) dose-response relationships; and (c) the mechanisms and moderators of change in these outcomes. In this section we detail recommendations for future research, in addition to practical considerations (e.g., study design) for the examination of physical activity's effects on well-being.

Alternate Modes of Physical Activity

Although aerobic exercise interventions comprise the majority of studies included in meta-analyses and systematic reviews of physical activity's effects on psychological and cognitive health, results of a growing number of non-aerobic exercise interventions (e.g., strength and flexibility training, Tai Chi) suggest examination of alternate modes of physical activity is warranted. For example, meta-analyses have

suggested that resistance-based exercise may result in the largest reductions in depressive and anxiety symptoms (Arent et al., 2000; Conn, 2010). In the cognitive literature, meta-analyses and RCTs have observed cognitive benefits of non-aerobic exercise modes similar to those of aerobic exercise (Colcombe & Kramer, 2003; Northey et al., 2017). For example, Voss and colleagues (2010) observed improvements in brain functional connectivity and older adults' performance on executive function tasks after 6 and 12 months of training in a non-aerobic, stretching and toning group.

Interventions targeting positive psychological states also suggest similar effects of aerobic (i.e., walking) and resistance training (i.e., toning/flexibility/stretching) programs on self-efficacy and physical self-worth (Elavsky et al., 2005; Gothe et al., 2011). However, the physical self-esteem subdomains (i.e., physical condition, body attractiveness, physical strength esteem) may be differentially influenced by physical activity modality. Gothe and colleagues (2011) noted that individuals randomized to a flexibility/toning group reported greater improvements in body attractiveness and physical strength esteem, likely due to the nature of the program and subsequent improvements in muscular strength. Individuals assigned to the walking group reported improvements in the physical condition and strength esteem. Despite these variations between groups, older adults in both conditions reported improvements in overall physical self-worth, suggesting various exercise modes may contribute similarly to more global perceptions of physical self-esteem.

The effects of complementary exercise, such as yoga or Tai Chi, have also increasingly been explored. Patel, Newstead, and Ferrer (2012) documented greater effects of yoga practice compared with conventional exercise on mental health status (SMD = 0.65) across 18 studies ($N=649$ adults aged 60+ years). Although a non-significant effect of yoga was observed for depression (SMD = -0.57), findings across the studies included in the review were mixed. Elavsky and McAuley (2007) also provided preliminary evidence that yoga may be effective in enhancing certain aspects of self-esteem in post-menopausal women. Women assigned to a walking condition reported improvements in physical condition, strength, and body attractiveness esteem, and women in the yoga group reported improvements in body attractiveness esteem after the 4-month intervention compared to a control condition. However, no increases in global self-esteem or physical self-worth were observed in either group.

In a meta-analysis on cognitive health by Gothe and McAuley (2015), yoga practice led to improvements in attention, processing speed, executive function, and memory across 15 RCTs ($g = 0.33$) and 7 acute bout studies ($g = 0.56$). Further, effects sizes were similar to those reported in relation to aerobic exercise (Smith et al., 2010). In older adults specifically, Gothe and colleagues (2014; 2013) observed greater improvements in working memory and executive function after an acute bout of yoga, compared to aerobic exercise, and after 8 weeks of yoga practice, compared to a stretching-strengthening control. Likewise, Eyre and colleagues (2016) observed improvements in brain functional connectivity and visuospatial memory in a small sample of older adults assigned to 12 weeks of hatha yoga compared to a memory enhancement training control. Taylor-Piliae and colleagues (2010) also provided evidence suggesting Tai Chi may lead to greater improvements in cognitive functioning in older adults compared with aerobic exercise. These findings have been supported by Northey and colleagues (2017) who observed significant effects of Tai Chi on cognitive function across four studies included in their meta-analysis. As findings are preliminary and generally diverse, researchers acknowledge that larger, prospective studies examining the effects of alternative exercise modalities on correlates of subjective well-being in older adults are needed.

Dose-Response

While dose-response relationships of exercise on negative psychological states and cognitive function have been examined, findings are equivocal. In relation to depression and anxiety, evidence suggests programs that are shorter in length (i.e., 3-12 weeks) and lower in intensity may have the largest effects compared with longer programs (i.e., 12+ weeks) and those of moderate and vigorous intensities. Barbour and Blumenthal (2005) found that in individuals aged 20-45 years, activity at a lower energy expenditure failed to provide significant reductions in depressive symptoms. However, researchers contend that older adults may respond differently to physical activity interventions compared to their younger counterparts (Arent et al., 2000; Herring et al., 2010). Thus, exercise trials of low intensity and short duration may be leveraged to provide the greatest reductions in negative symptomology in late life. While it remains unclear as to why shorter and lower intensity programs may elicit larger improvements in older adults' negative symptomology, it is possible that adherence is higher (Herring et al., 2010). Studies have also proposed that improvements may be due to participants being low-fit and previously sedentary, making low intensity physical activity more enjoyable and a more achievable goal. However, maintenance of these effects beyond the end of the intervention is unknown. Studies comparing the effects of various doses of exercise on negative states and including long-term follow-up assessments after program cessation may reduce these knowledge gaps.

Observational studies have consistently described a dose-response relationship between total volume of physical activity and cognitive function in older adults (Blondell et al., 2014; Xu et al., 2011). Fanning and colleagues (2017), using isotemporal substitution models, found that replacing 30 minutes of sedentary time with 30 minutes of moderate-to-vigorous physical activity resulted in improvements in performance on working memory and executive function tasks across 247 older adults. However, replacing sedentary time with light intensity activity did not confer the same cognitive benefits. Meta-analyses have provided more details on dose-response; however, findings have been mixed and are limited by design issues across RCTs. Northey and colleagues (2017) provided important evidence in support of the comprehensive physical activity guidelines including both aerobic exercise and resistance training. Findings also indicated that exercise sessions of a moderate duration (i.e., >45 to ≤60 minutes) and moderate or vigorous intensity may be most beneficial to older adults' cognitive functioning. Smith and colleagues (2010), on the other hand, observed positive cognitive outcomes across physical activity intensity levels. These preliminary and contrasting findings across studies indicate the need for further research examining the effects of exercise duration and intensity on older adults' cognitive functioning.

Moreover, Voss and colleagues (2014) have argued that daily moderate-to-vigorous physical activity may not offset the negative impacts of prolonged sedentary behavior on brain health and cognitive function. In this review, the authors provide compelling evidence of a common mechanistic pathway of cognition between moderate-to-vigorous physical activity and sedentary behavior. Certainly, more research examining the independent effects of sedentary behavior and interactive effects with light and moderate-to-vigorous physical activity is warranted. The conclusions drawn by Voss and colleagues (2014) suggest that neither sedentary time replacement nor increased physical activity should be promoted in isolation, but that combined efforts targeting the entire physical activity spectrum (e.g., light activity, moderate-to-vigorous physical activity, breaking up sedentary time) may most effectively benefit older adults' cognitive function. Findings across these studies indicate a need for additional RCTs investigating how various doses of physical activity are associated with different levels of cognitive function and, in turn, well-being.

As there has been little investigation of dose-response relationships between physical activity, positive psychological states, HRQL, and subjective well-being more research in these areas is needed. Studies have suggested that shorter interventions and light intensity exercise may have larger effects on HRQL (Gillison et al., 2009; McAuley et al., 2008). Likewise, Martin and colleagues (2009), in one of the few RCTs to examine the dose-dependent effects of exercise on HRQL, observed greater improvements in mental health status among participants assigned to the lowest dose of exercise when compared with the control group. However, more evidence is needed to verify the effects of lower volumes of physical activity on psychological health and HRQL, as this study also observed increases in physical and mental health status among participants in the highest dose group (i.e., exceeding physical activity recommendations). Taken together, the evidence across the literature suggests the effects of various doses of physical activity may differ across domains of well-being. Studies that aim to identify the physical activity dose or combination of doses (i.e., intensity + bout duration + mode + trial length) that optimize psychological, cognitive, and HRQL responses, and thereby subjective well-being, are needed to reconcile these differential effects.

Mechanisms and Moderators

Studies have tested a number of mechanisms thought to explain the effects of physical activity on psychological states and cognitive function. Cardiorespiratory fitness is arguably the most studied mediator in older adults, partially due to a focus on aerobic physical activity that predominates the literature (Blake et al., 2009; McAuley et al., 2004; Prakash, Voss, Erickson, & Kramer, 2015). However, findings suggest that change in cardiorespiratory fitness is an unlikely mechanism of exercise's effects on well-being responses.

Other potential physiological mechanisms of the physical activity—self-related function relationship include physical activity-induced changes in neurotransmitters of the brain and endogenous opioids that are known to be associated with depression, anxiety and other mood constructs (Antunes, Stella, Santos, Bueno, & Mello, 2005; Morgan & O'Connor, 1988). While there is preliminary evidence for these mediators in younger individuals and within the context of acute physical activity (Antunes et al., 2005; Brosse, Sheets, Lett, & Blumenthal, 2002; Dinas, Koutedakis, & Flouris, 2011; Janal, Colt, Clark, & Glusman, 1984), it remains unclear as to how these biomarkers relate to the influence of regular exercise on psychological health in older adults.

Consistent with the model proposed by McAuley and Morris (2007), there is a body of evidence that indicators of self-related function may themselves be mediators of the more distal relationship between physical activity and subjective well-being (Awick et al., 2017b; Elavsky et al., 2005; McAuley et al., 2006; Mudrak et al., 2016; Rejeski & Mihalko, 2001). Awick and colleagues (2017b) found that previously

sedentary older adults who increased their levels of moderate-to-vigorous physical activity after a 6-month exercise program reported significant reductions in a latent conceptualization of psychological distress (i.e., depression, anxiety, stress, sleep disturbance). Reduced distress was in turn significantly associated with improvements in satisfaction with life.

In relation to positive psychological states, Arent and colleagues (2000) discussed the use of physical activity as a mastery experience through which individuals may increase their exercise self-efficacy which, in turn, may contribute to more effective coping and better mood. Elavsky and colleagues (2005) reported that increased physical activity was positively associated with physical self-worth, self-efficacy, and positive affect in older adults 6 months after completing a 6-month physical activity intervention. Increased self-efficacy and positive affect were, in turn, significantly associated with greater satisfaction with life. Further, after a 4-year follow-up period (5 years from baseline), increases in physical activity were related to improvements in physical self-worth and positive affect, and these improvements in positive affect observed were directly associated with increased satisfaction with life. Importantly, the direct effect of physical activity on satisfaction with life was not significant at either time point. Thus, positive psychological states may at least partially mediate the influence of physical activity on QoL, and these effects may be maintained years after programs end. In the context of public health, these findings not only highlight the capacity of exercise interventions for improving a host of negative and positive components of self-related function, but also suggest these improvements may be at least partially responsible for lasting improvements in subjective well-being and life satisfaction.

Mechanisms of cognitive change frequently explored include brain volume, brain activity and connectivity, and neurogenesis (Bherer et al., 2013; Erickson & Kramer, 2008). Specifically, these mechanisms are: white and gray matter volumes, structural integrity, synaptic plasticity, growth factors (e.g., brain-derived neurotrophic factor [BDNF], insulin-like growth factor [IGF-1]), brain vasculature, inflammation, and neuroendocrine function (Voss et al., 2014). For example, Erickson and colleagues (2011) provided evidence relative to the effects of aerobic exercise and cardiorespiratory fitness on brain volume, neurogenesis, and cognitive functioning. Hippocampal volumes after a one-year RCT increased in older adults assigned to a walking program and decreased among those assigned to a stretching control group. Further, increases in cardiorespiratory fitness (as measured by a maximal graded exercise test) and serum BDNF were correlated with these increases in hippocampal volume. Although fitness and BDNF were not associated with participants' performance on a spatial memory task across the intervention, increases in hippocampal volume in the walking condition were associated with improvements in performance on the memory task.

Likewise, Voss and colleagues (2010) observed increased functional connectivity, which, was correlated with improved executive function in older adults participating in 12-month walking and stretching/toning programs. While these studies represent some of the few to comprehensively examine relationships among exercise training, neural mechanisms, and cognitive function, findings represent correlated change. The literature is rich with studies investigating causal relationships between physical activity and brain structure and function (Prakash et al., 2015); yet, few have extended Erickson et al. (2011) and Voss et al.'s (2010) findings using structural tests of mediation of the causal pathway from exercise training to brain structure and function to cognitive function.

Despite growing knowledge of mediators along the pathway between physical activity and subjective well-being, less is known about the moderators. In this chapter, we have suggested that intervention (e.g., program length, activity mode) and population (i.e., healthy v. clinical) characteristics may modify the effects of physical activity on well-being outcomes in older adults. However, less research has focused on person-level moderators, such as gender, age, personality, and baseline well-being. Netz and colleagues (2005) observed greater improvements in well-being in young-old adults ($d = 0.20$) when compared with old-old adults ($d = 0.11$) across 36 studies. As fewer well-being outcomes were tested in old-old adults (13 v. 159 in young-old), further investigation of physical activity's effects on well-being in the oldest old is critical. Although studies have provided evidence of physical activity's effects on well-being in older women and men separately (McAuley et al., 2008; Vallance, Eurich, Lavalley, & Johnson, 2012), the differential effects of physical activity on well-being by gender are equivocal (Netz et al., 2005). Research has also shown that personality traits (e.g., neuroticism, extroversion, agreeableness) may predict satisfaction with life, happiness, negative affect, positive affect, and physical activity (Artese, Ehley, Sutin, & Terracciano, 2017; DeNeve & Cooper, 1998). Yet, how personality and physical activity may interact in effecting change in well-being is unknown. We also might expect that individuals with lower levels of well-being or physical activity at the beginning of an exercise intervention may stand to benefit most. For example, Reed and Buck (2009) reported that improvements in positive affect across 105 aerobic exercise studies was greatest in individuals with the lowest levels of positive affect at program initiation ($d = 0.81$ [lowest tertile] v. $d = 0.26$ [highest tertile]). Similarly, Netz and colleagues (2005) reported greater

increases in well-being in sedentary versus non-sedentary adults ($d = 0.35, 0.17$, respectively). Unfortunately, most of these studies have not focused on moderators within older adults specifically even though aging researchers have stressed that modifying factors, such as baseline perceptions, may be more important in older adults compared with younger adults (Lehnert et al., 2012).

Other Considerations

In addition to the areas detailed above, there are other practical considerations for research investigating relationships among physical activity, psychological health, cognition, and well-being. First, studies suggest a positive relationship between physical activity and global well-being; however, due to a lack of experimental studies, few meta-analyses and systematic reviews have focused on well-being or global QoL in older adults. Therefore, more RCTs and reviews are warranted to provide more evidence of physical activity's influence on subjective well-being. Future research in this area should be explicit in their definitions of well-being and QoL, and, as such, carefully consider the measures utilized.

Similarly, design limitations noted across meta-analyses and reviews in psychological and cognitive health warrant additional RCTs. For negative psychological states, it has become a challenge for researchers to design adequate placebo/attentional control groups given that center-based exercise programs may include other factors that facilitate reductions in negative symptomology (Hawley-Hague et al., 2014; Hawley-Hague, Horne, Skelton, & Todd, 2015). For example, the level of social support inherent in many exercise training interventions may be effective in and of itself for improving negative affective responses (Ehlers et al., 2017; McAuley & Blissmer, 2000); therefore, it will be important to identify the individual role of physical activity for improving psychological states independent of other psychosocial elements. While previous research has demonstrated that a home-based (i.e., non-social) physical activity program is capable of improving positive affect (Awick et al., 2017a), further comparisons of social vs. non-social programs are warranted.

In relation to cognitive health, RCTs that test the effects of exercise against an active control condition may be needed to provide more definitive evidence of physical activity's effects on cognition (Northey et al., 2017; Young et al., 2015). While some RCTs have observed positive effects of exercise training compared to an active control (Kramer et al., 1999), Northey and colleagues (2017) found that exercise training only improved cognitive functioning when compared with education and no contact control conditions. No differences were observed when exercise was compared with active or social control conditions. RCTs may also help us to better understand interactions among physical activity, self-related function, cognition, health status, and well-being in older adults and to expand our knowledge of potential mediators, as recommended by Etnier, Nowell, Landers, and Sibley (2006).

Further, as subjective well-being is in part a cognitive assessment of one's life satisfaction (Diener, Oishi, & Lucas, 2003; Rejeski & Mihalko, 2001), understanding well-being perceptions among older adults with cognitive impairment or compromised health status represents a significant challenge (Logsdon, Gibbons, McCurry, & Teri, 2002). Deficits in attention, memory, and communication, in addition to psychological health symptoms such as depression and anxiety, can affect older adults' ability to understand questionnaire items and effectively communicate subjective states (Logsdon et al., 2002). The development of measures that validly assess well-being in individuals with cognitive impairment and dementia is needed (Thorgrimsen et al., 2003). Finally, although the temporal order of effects relative to self-related function and well-being is well-established, the directionality of the association between cognition and well-being is equivocal. Some studies suggest positive well-being is protective against age-related cognitive decline, while others argue the relationship may be reciprocal (Goveas et al., 2016). Therefore, the question remains—does greater life satisfaction lead to preserved cognitive function with aging, or does maintained cognitive function lead to greater perceptions of life satisfaction among older adults? Studies that investigate interactions among demographic (e.g., education, income), clinical (e.g., disease states), psychological, and cognitive correlates along the pathway between physical activity and well-being in older adults may help to answer this question, in addition to others relative to exercise mode, dose-response, and mediators of change (Chodosh, Kado, Seeman, & Karlamangla, 2007; Goveas et al., 2016; McAuley & Morris, 2007).

Similarly, evidence has suggested a bidirectional relationship between physical activity and the psychological, cognitive, and global aspects of well-being. For example, although individuals who are regularly active may be less likely to report depressive symptoms over time, individuals reporting fewer depressive and anxiety symptoms may also be more likely to participate in regular physical activity (Steinmo, Hagger-Johnson, & Shahab, 2014). Moreover, while a robust literature supports exercise in ameliorating cognitive decline in older adults, McAuley and colleagues (2011) also found that older adults' baseline self-regulation and executive function were predictive of their adherence to a randomized exercise trial. Finally, the framework proposed by McAuley and Morris (2007) posits well-being as a distal outcome

of physical activity; yet, empirical studies have suggested that individuals with greater life satisfaction may also be more likely to engage in health behaviors such as physical activity (Diener & Chan, 2011). Unfortunately, most studies investigating these reciprocal interactions between physical activity and subjective well-being have been conducted in the context of observational designs and in younger adult cohorts. RCTs in older adults are needed to better understand the temporal nature of the relationship between physical activity and well-being in this population.

Conclusion

The literature on physical activity and QoL, self-related function, and cognition provides a compelling argument in support of physical activity for improving subjective well-being in older adults. However, systematic, empirical evidence is lacking. Several factors outlined in this chapter have contributed to a lack of synthesis in the evidence on well-being in older adults. First, there is a need to better operationalize well-being and QoL in the context of physical activity interventions, as an array of definitions and measures have been used when referring to well-being (e.g., HRQL). We further contend that QoL and health status (i.e., HRQL) are distinct constructs and should, therefore, be measured and interpreted as such.

Next, a robust literature has evidenced the effectiveness of physical activity for improving self-related function and cognitive health, but few studies have linked these outcomes with well-being in older adults. Studies examining the pathway of changes in physical activity to mediators (e.g., self-related function and cognitive health) and global QoL in the context of RCTs are needed. The conceptual model proposed by McAuley and Morris (2007) provides a useful framework for filling this knowledge gap. Specifically, further scientific investigation in this area may help researchers to (1) define exercise prescriptions that optimize well-being in older adults; (2) clarify the temporal order of effects along this path; (3) better understand the mechanisms of change in well-being due to increased physical activity; and (4) identify for whom and under what conditions subjective well-being is most amenable to physical activity. Such knowledge may improve the design of interventions, programs, and health policies aimed at increasing well-being and QoL in older adults.

Both the psychological health and cognition literatures suggest aerobic and non-aerobic exercise programs may benefit well-being in older adults. The HRQL and psychological health literatures indicate that lower intensity programs may result in larger improvements in negative and positive psychological states. Findings within the cognition literature, on the other hand, suggest moderate-to-vigorous intensity exercise may be needed to elicit meaningful improvements in older adults' cognitive function. Additional research aimed at identifying the doses of physical activity that most effectively improve self-related function, cognition, health status, and well-being is needed. This includes further examination of trial length and type (e.g., home- v. center-based) and activity intensity, mode, and duration. Findings also suggest that less studied biological mechanisms (e.g., neurotransmitters, brain structure), in addition to cardiorespiratory fitness, warrant further investigation. Finally, although psychological factors, such as depression and self-efficacy, are generally accepted as proximal outcomes of physical activity, less is known about the temporal interaction between cognition and well-being (Goveas et al., 2016).

As medical technologies advance and the population continues to age, it is imperative to preserve the quality of extended years of life. Physical activity has emerged as an effective and attainable method for improving a number of important factors associated with well-being. While more research is needed to improve our understanding of lifestyle behaviors and well-being with advanced age, it is clear physical activity can be leveraged to improve subjective well-being in older adults.

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