Promoting Physical Activity: The Role of Commercial Physical Activity Apps and Online Social Networking

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Summary

Promoting engagement in physical activity is a public health priority. Commercial physical activity apps (e.g., Strava) present unparalleled opportunities to improve physical activity engagement, given they are highly accessible, convenient, cost-effective and afford widespread reach. Many of these apps also incorporate social networking functionalities (e.g., app communities, connections to existing social networking platforms such as Facebook, Instagram) that have the capacity to foster supportive interactions that are important to facilitating physical activity. There is a dearth of evidence regarding the capacity of commercial physical activity apps (and their social networking functionalities) to promote physical activity engagement. Therefore, the overarching aim of the present thesis was to provide a comprehensive understanding of the capacity of commercial physical activity apps (and their social networking functionalities) to support engagement in physical activity.

The program of research comprises five studies (four published, one currently under review). Study 1 was a systematic literature review, which synthesised the evidence on the effectiveness of physical activity apps and the additive value of existing social networking platforms. Overall, physical activity apps (largely developed for research purposes) were found to support improved physical activity engagement, and notably, existing social networking platforms demonstrated the potential to enhance the effectiveness of these apps.

Study 2 was a large cross-sectional study of adults (n = 1432) from the general population that evaluated the capacity of commercial physical activity apps (and their social networking functionalities) to support physical activity engagement. The use of commercial physical activity apps, along with app communities and existing social networking platforms, promoted higher physical activity engagement. In the same sample, Study 3 (n = 1274) aimed to determine how apps may support engagement in physical activity by examining associations with key psychological determinants of physical activity (i.e., social support,

self-efficacy, and motivation). The findings indicated that commercial physical activity apps have the potential to facilitate social support, and are positively associated with autonomous types of motivation (intrinsic and identified) and beliefs in one's ability to perform physical activity (self-efficacy). Trait competitiveness, but not trait social comparison, moderated the relationship between app use and physical activity such that app users with higher trait competitiveness engaged in more physical activity. Sharing physical activity to existing social networking platforms supported physical activity engagement via positive associations with self-efficacy, and receiving encouragement via positive associations with both self-efficacy and autonomous types of motivation (identified regulation). Conversely, engagement in comparisons on existing social networking platforms was negatively associated with physical activity engagement via lower self-efficacy and higher external regulation.

Study 4 examined the longitudinal associations between the use of commercial physical activity apps (and their social networking functionalities), psychological constructs (social support, self-efficacy, and motivation), and physical activity engagement over a 6-month period, in a subsample of Study 2; n = 731. Commercial physical activity app use and sharing physical activity behaviour to existing social networking platforms were associated with higher levels of physical activity over that timeframe. In addition, social support, self-efficacy, identified regulation and introjected regulation emerged as positive predictors of longer-term physical activity.

Study 5 evaluated the capacity of commercial physical activity apps to support physical activity engagement during a pandemic in a subsample of Study 2 (n = 408). Psychological (social support, self-efficacy, motivations) and mental health predictors (depression, stress, anxiety) of physical activity during the COVID-19 lockdown were also investigated. Commercial physical activity app use predicted physical activity during the COVID-19 lockdown, as did social support, self-efficacy and identified regulation. Self-

efficacy and identified regulation also mediated the positive relationship between app use and physical activity engagement.

Overall, the current program of research has progressed an important field, providing a novel insight into commercial physical activity apps (and their social networking functionalities). The findings provide evidence to indicate that commercial physical activity apps are beneficial in supporting physical activity engagement. The body of work is fundamental to informing the design and implementation of effective app-based physical activity interventions in future. This research, therefore, has significant implications for facilitating widespread improvements in physical activity engagement, and optimising population physical and mental health outcomes.

Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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CHAPTER 1: GENERAL INTRODUCTION

Chapter Overview

This introductory chapter provides a brief background to physical activity and the key determinants linked to physical activity behaviour, namely self-efficacy, social support, and motivation. Next, the potential for physical activity smartphone applications (apps) and online social networking to support physical activity engagement is discussed. Finally, a summary of the main aims of the thesis and content of the subsequent chapters is provided.

Physical Activity

Physical activity is critical to enhancing health outcomes. It is well documented that physical activity has many health benefits including a reduced risk of obesity, cardiovascular disease, stroke, hypertension, Type 2 diabetes, osteoporosis, and some types of cancer (colon and breast cancer) (Rhodes, Janssen, Bredin, Warburton, & Bauman, 2017; Warburton, Nicol, & Bredin, 2006). Physical activity is also known to enhance mental health outcomes (Chekroud et al., 2018), including reducing depression, anxiety and stress, and increasing positive affect (Buecker, Simacek, Ingwersen, Terwiel, & Simonsmeier, 2020; Rhodes et al., 2017; Schuch et al., 2019; Schuch et al., 2018). The World Health Organisation recommends engaging in 150 minutes of moderate or 75 minutes of vigorous aerobic activity per week and ≥ 2 days per week of muscle-strengthening activities to attain health benefits (World Health Organisation, 2020). Despite this, globally, 1.4 billion adults (28%) do not meet the physical activity guidelines (Guthold, Stevens, Riley, & Bull, 2018), with higher rates of inactivity reported in high-income Western countries including Australia where over half of the adult population is insufficiently active (Australian Institute of Health and Welfare, 2020). Concerningly, the COVID-19 pandemic threatens to further reduce physical activity engagement by limiting opportunities for physical activity (e.g., closure of indoor and outdoor physical activity facilities, cancellation of sporting competitions, isolation, social

distancing). Physical inactivity is a leading contributor to premature mortality worldwide (Guthold et al., 2018; World Health Organisation, 2020), and has a substantial negative economic impact, costing the Australian economy $555 million per year in direct healthcare expenses (Ding et al., 2016). Increasing engagement in physical activity is, therefore, a public health priority. The development of innovative, scalable interventions is fundamental to improving engagement in physical activity in order to achieve the World Health Organisation's target for physical inactivity reduction by 15% in 2030 (World Health Organization, 2019).

Theoretical frameworks can be used to provide guidance in relation to constructs that are antecedents of a behaviour (e.g., physical activity), and thus should be targeted by an intervention for behaviour change to occur (Michie & Prestwich, 2010). There are many theoretical constructs (>100) that are linked to physical activity including self-efficacy (beliefs in one's ability to perform physical activity), social support, attitudes, normative beliefs (perceptions about the expectations of significant others), outcome expectations (anticipated benefits of physical activity), and motivation (Choi, Lee, Lee, Kang, & Choi, 2017). A large body of evidence indicates that self-efficacy, social support, and motivation are among the most consistent and reliable predictors of physical activity (Bauman et al., 2012; Choi et al., 2017; Rhodes et al., 2017; Trost, Owen, Bauman, Sallis, & Brown, 2002). The importance of these constructs is further highlighted by a Scientific Statement from the American Heart Association recommending that physical activity interventions should incorporate strategies that foster self-efficacy, social support, and motivation for behaviour change (Artinian et al., 2010). It is, therefore, necessary to consider such psychological constructs in the development of effective approaches to support engagement in physical activity.

Physical Activity Self-efficacy

Physical activity self-efficacy is a core construct in many behaviour change theories and is frequently cited as the most consistent correlate of physical activity behaviour (Choi et al., 2017; Rhodes et al., 2017; Trost et al., 2002). More specifically, an umbrella review of 25 reviews (980 primary studies) found that self-efficacy had the strongest positive association with physical activity across all reviewed correlates (n = 117) (Choi et al., 2017). Evidence further suggests that self-efficacy is an important determinant of physical activity across the lifespan (Martins et al., 2021; Notthoff, Reisch, & Gerstorf, 2017) and in diverse subpopulations (e.g., disadvantaged groups, persons with chronic diseases) (Collado-Mateo et al., 2021; Craike et al., 2019). Self-efficacy plays an important role in the adoption of, and long-term adherence to, physical activity (Amireault, Godin, & Vézina-Im, 2013; Sallis, Hovell, & Hofstetter, 1992). A recent review examining mediators of physical activity interventions among adults has further identified that self-efficacy is an important agent of behaviour change (Rhodes, Boudreau, Josefsson, & Ivarsson, 2021). For example, Larsen et al. (2020) found that a web-based physical activity intervention facilitated an increase in self-efficacy, and in turn, improved engagement in self-reported and accelerometer-derived moderate-to-vigorous physical activity (MVPA) among women. Self-efficacy is, therefore, critical to the promotion of physical activity.

Social Support

Social support is embedded in many behaviour change theories (Bandura, 1999; Bronfenbrenner, 1977; Rosenstock, Strecher, & Becker, 1988), and has long been recognised as an important modifiable determinant of physical activity (McNeill, Kreuter, & Subramanian, 2006). There are many mechanisms through which social support is suggested to influence physical activity including: social comparison/social influence, access to information and resources, the provision of encouragement, enhanced self-esteem, and

minimising the negative effects of stress (Thoits, 2011). Additionally, in line with Social Cognitive Theory (Bandura, 1999) and existing research (Rovniak, Anderson, Winett, & Stephens, 2002), social support is documented to facilitate increased self-efficacy, the most consistent determinant of physical activity (Choi et al., 2017; Trost et al., 2002). An extensive body of evidence has demonstrated the importance of social support in facilitating physical activity engagement (Rhodes et al., 2021; Rhodes et al., 2017; Trost et al., 2002). First, research pertaining to specific types of social support, namely informational (i.e., knowledge), esteem (i.e., emotional) and companionship (i.e., partnership) (Chogahara, 1999), has shown that esteem support is particularly beneficial in promoting physical activity engagement (Cavallo et al., 2014; Kouvonen et al., 2011; Okun et al., 2003). Moreover, a meta-analysis documented that physical activity interventions incorporating social support (broadly) achieved greater effectiveness (Greaves et al., 2011). Farren, Zhang, Martin and Thomas (2017) further showed that participants who reported higher levels of social support for physical activity were significantly more likely to meet physical activity guidelines (both aerobic and strength guidelines). In a qualitative study, non-adherers to a 12-month physical activity program reported that greater social support would have facilitated increased compliance with the program (Larson, Mcfadden, McHugh, Berry, & Rodgers, 2018). Relatedly, lack of social support is a commonly cited barrier to an active lifestyle in the general population (Baillot et al., 2020; Herazo-Beltran et al., 2017). Innovative strategies should, therefore, be implemented to foster social support for physical activity, in line with recommendations by the World Health Organisation's Global Action Plan on Physical Activity 2018-2030 (World Health Organization, 2019).

Motivation

Motivation is also an important determinant of physical activity behaviour and is widely examined in relation to Self-determination Theory (Deci & Ryan, 1985). The central

tenant of this theoretical perspective is the distinction between autonomous (motivations on the basis of enjoyment or personal value) and controlling forms of motivation, such as motivations on the basis of internal (e.g., guilt, self-worth) or external pressures (e.g., obtain reward or avoid punishment) (Deci & Ryan, 1985). Autonomous types of motivation have consistently been linked to higher engagement in physical activity (Teixeira, Carraça, Markland, Silva, & Ryan, 2012) across the lifespan (Brunet & Sabiston, 2011). Notably, autonomous motivations predict long-term engagement in physical activity (Teixeira et al., 2012), imperative to attaining and maintaining physical and mental health benefits associated with physical activity. For example, Courtney et al. (2021) found that autonomous types of motivation was associated with higher levels of physical activity over a six-year period during the adolescent-to-adult transition. Autonomous types of motivation have also been shown to play an important role in physical activity engagement in highly inactive subpopulations. Specifically, Castonguay and Miquelon (2017) found that among adults with Type 2 diabetes, higher levels of autonomous forms of motivation were associated with a greater likelihood of meeting physical activity guidelines. Recent meta-analyses have documented that health interventions informed by Self-determination Theory effectively promote behaviour change (e.g., increased physical activity engagement), and these effects are attributed to positive changes in autonomous types of motivation (Ntoumanis et al., 2021; Sheeran et al., 2020). Sheeran et al. (2021) further found (in a meta-analysis) that interventions that effectively increased autonomous types of motivation generated more substantial changes in health behaviour (medium magnitude; d = .47) relative to those that did not improve such motivations (d = .13). The authors, therefore, concluded that autonomous motivations are an important target for behaviour change interventions (Sheeran et al., 2021).

It is clear that self-efficacy, social support, and autonomous types of motivation play an essential role in physical activity promotion and engagement. They should, therefore, be considered in the development of approaches that will effectively support physical activity engagement. The next section of this chapter discusses an innovative approach to facilitating engagement in physical activity.

Physical Activity Applications

Smartphone technology presents an opportunity to deliver large-scale interventions targeted at improving physical activity engagement, given that globally, there are more than 3.8 billion smartphone owners (Pew Research, 2019). In particular, the rapid growth of commercially available mobile health apps presents novel prospects for health promotion (Aitken, Clancy, Nass, & IQVIA, 2017). Commercially available physical activity apps are ubiquitous, accounting for the majority of health apps, and are expected to increase 87% faster than any other category of health app (Grand View Research, 2017). Commercial physical activity apps are not only highly accessible, but also convenient, cost-effective and afford widespread reach. They are, therefore, an ideal medium to support physical activity engagement in the broader population, including in rural and remote areas where there are fewer opportunities to engage in physical activity, and consequently individuals are less active and experience poorer health outcomes (Australian Bureau of Statistics, 2019). Additionally, commercial physical activity apps have been documented to incorporate a range of behaviour change techniques (e.g., self-monitoring, feedback, goal-setting, demonstration of behaviour) (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018), many of which have been shown to facilitate physical activity engagement in the general adult population (Greaves et al., 2011; Michie, Abraham, Whittington, McAteer, & Gupta, 2009). Commercial physical activity apps provide unparalleled opportunities to support physical activity engagement, which has further been recognised during the COVID-19 pandemic. Specifically, commercial physical activity apps have the capacity to facilitate physical activity remotely

in the home, and therefore, could be particularly valuable in supporting physical activity during non-pandemic as well as pandemic times.

Despite the ubiquity of commercial physical activity apps, there is limited robust research evaluating their effectiveness. To date, the literature has largely focused on newly developed physical activity apps for research purposes rather than commercially available apps. This is problematic as commercial apps are those that are accessed and used by the general public. Nevertheless, existing reviews examining physical activity apps (commercial and research apps) have only documented modest evidence of their effectiveness to positively influence physical activity behaviours (Coughlin, Whitehead, Sheats, Mastromonico, & Smith, 2016; Romeo et al., 2019; Schoeppe et al., 2016). Thus, there is considerable scope to improve the effectiveness of physical activity apps. Determining the specific features of physical apps that are linked to physical activity engagement could be key to maximising the effectiveness of these apps. It must be noted that the level of engagement with physical activity apps plays an important and well-substantiated role in the effectiveness of such apps (Romeo et al., 2019; Schoeppe et al., 2016). More specifically, existing research has documented a "dose-response" relationship, such that increased app engagement (i.e., exposure to intervention content) is linked to superior behavioural outcomes (Schoeppe et al., 2016; Smith & Liu, 2020). Typically, smartphone based physical activity interventions report declines in engagement (Romeo et al., 2019), and therefore, evaluating the value of specific features to improve engagement with physical activity apps may be important to enhance their overall effectiveness in relation to physical activity behaviour.

Online Social Networking

Online social networking has the potential to improve the effectiveness of health interventions, such as commercial physical activity apps. Online social networking refers to

online environments that allow users to construct a personal profile and build a network of connections with other users, such as Facebook, Instagram, and Twitter (Lim, Wright, Carrotte, & Pedrana, 2016). They are suggested to be beneficial in their capacity to foster the provision of social support akin to that received through face-to-face interactions (Santarossa, Kane, Senn, & Woodruff, 2018). Online social networking overcomes many of the challenges associated with face-to-face support (e.g., labour intensive, cost prohibitive) and affords advantages including greater accessibility of immediate and continuous support, anonymity, and wide reach. They may also be particularly valuable during current (COVID-19) and future pandemics when face-to-face social support is restricted.

Two distinct types of online social networks are represented in the research to date: (1) health-focused social networks (e.g., networks developed by a researcher or integrated into health apps), and (2) existing online social networks (e.g., Facebook) (Maher et al., 2014). Reviews of health interventions (largely web-based) that incorporate online social networks have reported only modest evidence supporting the effectiveness of such interventions (Laranjo et al., 2015; Maher et al., 2014). Notably, both Maher et al. (2014) and Laranjo et al. (2015) suggested that existing social networking platforms show potential in enhancing the effectiveness of health interventions. Existing social networking platforms are purported to be beneficial given their capacity to leverage existing networks. This is in line with several theoretical perspectives (e.g., Social Comparison Theory, Theory of Planned Behaviour) documenting that proximal referent groups (i.e., friends, family, peers) exert the greatest influence on health behaviour (Ajzen, 1991; Festinger, 1954). Preliminary evidence suggests that existing social networking platforms have the capacity to facilitate increased social support (Oeldorf-Hirsch, High, & Christensen, 2019), as noted above, a construct shown to play an important role in promoting physical activity engagement (Rhodes et al., 2017; Trost et al., 2002). Finally, existing social networking platforms such as Facebook,

Instagram and Twitter are well integrated into daily life, immensely popular, and report high levels of sustained engagement (Statista, 2018). Interventions that incorporate existing social networks may, therefore, achieve heightened effectiveness in their capacity to reach large audiences and sustain high levels of engagement.

A growing body of research examining the content of commercial physical activity apps has documented that many incorporate social networking functionalities (Bondaronek, et al., 2018; Mollee, Middelweerd, Kurvers, & Klein, 2017). More specifically, they incorporate functionalities that facilitate supportive interactions with other app users (app communities; allowing users to share physical activity, provide/receive encouragement, engage in competitions within the app) or connections to existing social networking platforms (e.g., Facebook, Instagram). Leveraging the social networking functionalities of commercial physical activity apps, in particular existing social networking platforms could be key to maximising app effectiveness. It is imperative to determine the capacity of these social networking functionalities to support engagement in physical activity, and their subsequent potential to enhance the effectiveness of commercial physical activity apps.

Aims

The overarching aim of this program of research was to provide a comprehensive understanding of the capacity of commercial physical activity apps (and their social networking functionalities) to support engagement in physical activity. The timing of this program of research also provided the unique opportunity to explore the value of commercial physical activity apps in facilitating engagement in physical activity during a pandemic, when opportunities to be active have been limited.

Outline of the Thesis

The overarching thesis aim was achieved by conducting a series of studies that are described in each of the subsequent chapters. In Chapter 2 (Study 1), a systematic review was conducted to examine the effectiveness of physical activity apps, and the additive value of existing social networking platforms. Chapter 3 presents Study 2, a cross-sectional examination of the associations between commercial physical activity app use (and their social networking functionalities) and physical activity behaviour. Chapter 4 presents Study 3, which aimed to ascertain the psychological mechanisms (i.e., social support, self-efficacy, and motivation) underlying the capacity of commercial physical activity apps (and social networking functionalities) to support physical activity engagement. The role of individual difference characteristics (i.e., trait competitiveness and trait social comparisons) were also explored. Chapter 5 presents Study 4, a longitudinal examination of the associations between commercial physical activity app use (and their social networking functionalities), psychological constructs (social support, self-efficacy, and motivation) and physical activity behaviour over a 6-month period.

Study 5 (Chapter 6) had initially been conceptualised as a randomised controlled trial to evaluate the effectiveness (utilising accelerometer-derived physical activity) and feasibility of an intervention incorporating a commercial physical activity app (and its social networking functionality), for which ethical approval had been obtained (SBREC8525) and recruitment commenced. However, due to the onset of the COVID-19 pandemic, this trial had to be abandoned. Instead, Study 5 examined the capacity of commercial physical activity apps (and their social networking functionalities) to support physical activity during the COVID-19 pandemic and resultant ‘lockdown’. This study also examined the psychological (social support, self-efficacy, motivation) and mental health predictors (depression, stress, anxiety) of physical activity during this time. The final chapter (Chapter 7) presents a discussion of the

program of research, including theoretical and practical implications and avenues for future research.

All chapters in this thesis (aside from Chapters 1 and 7) are formatted as manuscripts for publication. Chapters 2 and 3 (Studies 1 and 2) have been published in the *Journal of Medical Internet Research*, and Chapters 4 and 6 (Studies 3 and 5) have been published in *Psychology of Sport and Exercise*. Chapter 5 (Study 4) is currently under review. Consequently, there is some repetition of information in the Introduction and Method sections of each chapter.

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CHAPTER 2: STUDY 1

A Comparison of Physical Activity Mobile Apps With and Without Existing Web-Based Social Networking Platforms: Systematic Review

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Abstract

Background: Physical activity mobile apps present a unique medium to disseminate scalable interventions to increase levels of physical activity. However, the effectiveness of mobile apps has previously been limited by low levels of engagement. Existing online social networking platforms (e.g., Facebook and Twitter) afford high levels of popularity, reach, and sustain engagement, and thus, may present an innovative strategy to enhance the engagement, and ultimately the effectiveness of mobile apps. **Objective:** This study aimed to comparatively examine the effectiveness of, and engagement with, interventions that incorporate physical activity mobile apps in conjunction with and without existing online social networking platforms (e.g., Facebook and Twitter). **Methods:** A systematic review was conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Guidelines. A systematic search of the following databases was conducted: Medline, PsycINFO, Web of Science, Scopus, CINAHL, ProQuest, SPORTDiscus, EMBASE, and Cochrane. According to the comparative objective of this review, two independent literature searches were conducted. The first incorporated terms related to apps and physical activity; the second also incorporated terms related to online social networking. The results of the two searches were synthesized and compared narratively. **Results:** A total of fifteen studies were identified, ten incorporated a physical activity app alone and five incorporated an app in conjunction with an existing online social networking platform. Overall, ten of the fifteen interventions were effective in improving one or more physical activity behaviours. Specifically, improvements in physical activity behaviours were reported in seven of the ten interventions incorporating physical activity apps alone and in three of the five interventions incorporating physical activity apps in conjunction with existing online social networking platforms. Interventions incorporating physical activity apps alone demonstrated a decline in app engagement. In contrast, the physical activity apps in

conjunction with existing online social networking platforms showed increased and sustained intervention engagement. **Conclusions:** The interventions incorporating physical activity apps in conjunction with and without existing online social networking platforms demonstrated effectiveness in improving physical activity behaviours. Notably, however, the interventions that incorporated existing online social networking platforms achieved higher levels of engagement than those that did not. This review provides preliminary evidence that existing online social networking platforms may be fundamental to increase engagement with physical activity interventions.

Introduction

Physical inactivity is a global pandemic. Globally, 1.4 billion adults (28%) are not meeting the physical activity guidelines (150 min of physical activity per week), a figure that is steadily increasing (Guthold, Stevens, Riley, & Bull, 2018). This is of public health concern given the consistently documented benefits of physical activity, including a reduced risk of cardiovascular disease, hypertension, osteoporosis, diabetes mellitus, obesity, mental illness, and premature mortality (Barbour, Edenfield, & Blumenthal, 2007; Lee et al., 2012; Warburton, Nicol, & Bredin, 2006). Thus, it is important to develop innovative, scalable interventions to increase levels of physical activity.

Advancements in mobile technology, specifically the development of mobile apps, present a unique medium to deliver interventions targeted at improving health behaviours. Mobile apps are software programs developed for mobile phones and tablets that hold potential to influence health behaviours owing to their widespread reach, accessibility, and convenience (Payne, Lister, West, & Bernhardt, 2015). Recently, there has been a proliferation of mobile health apps, with estimates of over 318,000 available for download, double the number available 2 years ago (Aitken, Clancy, Nass, & IQVIA, 2017). Among mobile health apps, physical activity apps account for the largest proportion (30%) and are expected to increase 87% faster than any other category of health app (Grand View Research, 2017). Despite the ever-increasing ubiquity of physical activity mobile apps, previous reviews have only demonstrated modest evidence from such apps in terms of the magnitude of their effectiveness to positively influence physical activity behaviour (Covolo, Ceretti, Moneda, Castaldi, & Gelatti, 2017; Romeo et al., 2019; Schoeppe et al., 2016; Zhao, Freeman, & Li, 2016). This indicates that there is potential to improve the effectiveness of physical activity mobile apps.

The effectiveness of mobile apps is influenced by levels of engagement with the app (Schoeppe et al., 2016). Specifically, a dose-response has been identified, such that increasing levels of engagement, and thus greater exposure to intervention content, is associated with improved behavioural outcomes (Schoeppe et al., 2016). Unfortunately, commercial research has identified a lack of commitment to sustained engagement with health and physical activity apps, reporting that few individuals (10%) engage with downloaded apps for more than seven days (Dennison, Morrison, Conway, & Yardley, 2013; Grady et al., 2018). An initial review of interventions incorporating physical activity apps also revealed rapid declines in app engagement over intervention periods of 3 and 9 months (Jee, 2017). A more recent review further documented that interventions incorporating apps were effective only in the short term (<3 months), and this was purportedly linked to declining levels of engagement over time (Romeo et al., 2019). This is concerning given that long-term engagement in physical activity behaviours is important to attain any associated health benefits (Warburton et al., 2006). It is clear that strategies are needed to enhance engagement with mobile apps targeted at increasing physical activity. This, however, requires a greater understanding of the specific features of mobile apps that may augment engagement, and ultimately enhance their effectiveness.

An important consideration in the endeavour to improve the effectiveness of physical activity mobile apps is the appropriate utilisation of behaviour change theory. This is fundamental as the existing empirical literature has consistently identified that effective physical activity interventions are informed by theory (Glanz & Bishop, 2010; Webb, Joseph, Yardley, & Michie, 2010). However, previous research within the realm of physical activity interventions incorporating mobile apps has documented that the utilisation of behaviour change theory is largely lacking (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018; Conroy, Yang, & Maher, 2014; Cowan et al., 2013; Mollee, Middelweerd, Kurvers, & Klein,

2017). In addition, among the physical activity apps that are informed by theory, a diverse range of theories have been utilised including the Health Belief Model; Transtheoretical Model; Theory of Planned Behavior; and Social Cognitive Theory (Cowan et al., 2013). This has limited the formation of conclusions regarding the most appropriate theoretical foundation(s) to inform the development of apps (Stuckey, Carter, & Knight, 2017).

Behaviour change theories are important in isolating specific features to incorporate into an intervention that will effectively facilitate behaviour change. Given this, it is not surprising that an emerging body of research examining the content of physical activity mobile apps has identified that apps are lacking in the inclusion of features underpinned by behaviour change theory (Bondaronek et al., 2018; Conroy et al., 2014; Cowan et al., 2013; Mollee et al., 2017). Nevertheless, the limited theory-driven research to date has identified one particular feature, namely social support, that has been consistently incorporated into physical activity mobile apps and is underpinned by a myriad of behaviour change theories (Bondaronek et al., 2018; Conroy et al., 2014; Cowan et al., 2013; Mollee et al., 2017). Social support is commonly integrated into apps via online social networking, which allows individuals to construct a personal profile and connect with other users (Mollee et al., 2017). Online social networks incorporated into physical activity mobile apps have a range of functionalities, including features that allow users to share physical activity data, receive *likes* and comments on their behaviour (facilitating social interactions), and thus foster the provision of social support (Mollee et al., 2017).

Typically, social support has been documented as a fundamental component of health interventions delivered face to face and has been associated with increased intervention engagement (Perski, Blandford, West, & Michie, 2017; Poirier & Cobb, 2012) and sustained behaviour change (Courneya, Plotnikoff, Hotz, & Birkett, 2000). Although face-to-face interventions may effectively facilitate high levels of support through interpersonal

interactions, several limitations including time, cost, and resource intensiveness may hinder the viability of such interventions. Online social networks overcome many of the barriers of face-to-face interventions and afford several advantages including greater accessibility of immediate and continuous support, anonymity, and wide reach. Additionally, online social networks incorporated into web-based interventions targeting weight-related outcomes (e.g., body weight and body mass index [BMI]) have demonstrated that the support provided is comparable with that attained in face-to-face interventions (Bennett et al., 2010). Thus, it has been suggested that the support provided by online social networks may emulate the interpersonal support achieved through face-to-face interventions (Santarossa, Kane, Senn, & Woodruff, 2018). Evidently, online social networking may be valuable in facilitating the provision of social support and fundamental in enhancing intervention engagement and thus effectiveness.

Previous research has ascertained two types of online social networks incorporated into health interventions: (1) health-focused social networks (i.e., networks developed by a researcher or integrated into health apps allowing users to connect with other users), and (2) existing social networking platforms (e.g., Facebook and Twitter) (Laranjo et al., 2015; Maher et al., 2014). In total, two systematic reviews have examined interventions (predominately web-based) targeting health behaviours, including obesity, physical activity, sexual health, and smoking cessation, that either incorporated or were exclusively delivered via online social networks (health-focused and existing) (Laranjo et al., 2015; Maher et al., 2014). These reviews demonstrated positive effects of online social networking in modifying health behaviours. However, neither review was able to identify the differing effectiveness of health-focused and existing online social networks on influencing health outcomes and levels of engagement, as the two types of social networks were not evaluated independently. Notably, in both reviews, it was proposed that the inherent nature of existing online social

networking platforms may be harnessed to address issues of engagement and reach, ultimately enhancing the effectiveness of health interventions (Laranjo et al., 2015; Maher et al., 2014).

A recent meta-analysis (An, Ji, & Zhang, 2017) of interventions (e.g., web-based, face-to-face, and text messaging) targeting weight-related behaviours (e.g., physical activity) and body weight status (e.g., BMI) that either incorporated or were exclusively delivered via existing online social networking platforms reported that these interventions produced significant reductions in body weight, BMI, and waist circumference, and significantly increased the average number of daily steps. This demonstrates that interventions incorporating, or exclusively delivered via existing online social networking platforms, have the capacity to effectively modify a range of health-related outcomes. This may be attributed to the unique nature of existing online social networking platforms, including their enormous popularity and widespread reach, with over 2.46 billion users worldwide, a figure that is continuing to rise (Statista, 2019). Additionally, existing online social networking platforms achieve high levels of sustained engagement, with estimates that 76% of Facebook users log in daily, 51% engage multiple times per day, and 70% continue to use the platform after 24 months (Statista, 2019). Therefore, interventions that incorporate existing online social networking platforms may achieve heightened effectiveness in their capacity to reach large audiences and sustain high levels of engagement.

Previously, no review has exclusively examined the effectiveness of interventions that incorporate physical activity mobile apps in conjunction with existing online social networking platforms. The high prevalence of physical activity mobile apps, coupled with the promising capabilities of existing online social networking platforms to augment app effectiveness, highlights an important avenue that warrants examination. Thus, this review examined the influence of existing online social networking platforms on the effectiveness of,

and engagement with, mobile apps that target physical activity. To isolate the influence of existing online social networking platforms, this review provides a comparison between interventions that incorporate physical activity mobile apps in conjunction with and without existing online social networking platforms.

Method

Overview

The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines (Moher, Liberati, Tetzlaff, Altman, & Group, 2009) (see Figures 1 and 2) and was registered with the International Prospective Register of Systematic Review (registration number CRD42018106456). An academic health librarian assisted with the development of the search strategy. The search strategy incorporated key terms and thesaurus terms related to mobile apps (e.g., application, app, mobile phone, and iPhone), physical activity (e.g., exercise, fitness, sports, inactive, and sedentary behaviour) and online social networks (e.g., social network, social medium, Facebook, Twitter, and Instagram). However, according to the comparative aims of this review, two independent searches were conducted, which differed such that one incorporated the terms related to apps and physical activity (app-alone search) and the other also incorporated the terms related to online social networking (app online social networking search). Both searches were conducted on the July 3, 2018, using the following nine databases: Medline, PsycINFO, Web of Science, Scopus, CINAHL, ProQuest, SPORTDiscus, EMBASE, and Cochrane. The search results were limited to the English language, peer-reviewed, and year of publication between 2007 (the year smartphones were introduced) and the July 3, 2018.

Inclusion Criteria and Study Selection

Studies from the two independent searches were selected if (1) a mobile app was incorporated as the main component of the intervention; (2) the primary or secondary outcome was to promote physical activity; (3) physical activity outcomes were reported; and (4) baseline and postintervention assessments of physical activity outcomes were included. The inclusion criteria differed slightly between the two searches to fulfill the comparative aims of the review. Specifically, the first search, termed app-alone, attempted to exclusively isolate the effect of physical activity apps, such that studies were deemed relevant if they did not incorporate any type of online social network (health-focused or existing) or social component. Conversely, to ascertain the additive effects of an existing online social network over and above that of an app, the second search, termed app online social networking, required studies to specifically incorporate an existing online social networking platform (e.g., Facebook and Twitter) into their design. Caution was taken to ensure that any studies identified in the first database search (app-alone) relevant to the second search (app online social networking) or vice-versa were included in the appropriate pool of studies according to the predefined inclusion criteria. Included studies utilised an experimental or within-subjects pre-post design to determine the effectiveness of the intervention. Studies incorporating populations capable of engaging in physical activity were eligible for inclusion. In total, two reviewers independently screened the titles, abstracts, and full-text papers for eligibility and any disagreements were resolved by discussion. Forward (screening the citations of included studies) and backward (screening the reference lists of included studies) searching was conducted to ensure all relevant publications were identified.

Data Extraction

Data extraction was conducted by the first author using a standardised form developed for this review. Extracted information included sample characteristics, study design, features

of the mobile app, details of the online social network, physical activity outcomes (time points reported), any additional outcomes reported (e.g., engagement and psychosocial outcomes), and behaviour change theories reported.

Reporting of Methodological Characteristics

A 25-item tool devised by Maher et al. (2014) based on the Consolidated Standards of Reporting Trials (CONSORT) checklist (Moher et al., 2012) that examines reported methodological characteristics was used to assess methodological risk of bias. The tool has been used in previous reviews of health (Kemps et al., 2020) and mHealth interventions (Maher et al., 2014; Romeo et al., 2019) and was deemed to be relevant for this study as most of the items (20 out of 25) were applicable to both pre-post designs and randomised controlled trials. The checklist was scored according to the extent to which each item was (1) fulfilled; (0.5) partially fulfilled; and (0) not fulfilled. A higher score is indicative of a lower risk of bias. In total, two independent reviewers assessed all included studies, and any disagreements were discussed and resolved.

Data Synthesis

The primary outcome was physical activity behaviour. The secondary outcomes included engagement with the intervention and psychosocial outcomes related to physical activity. In line with the comparative aims of the review, the app-alone and app online social networking studies were compared in relation to both the primary and secondary outcomes. To determine whether the interventions effectively improved physical activity behaviour, *P* values were evaluated. Specifically, interventions that were randomised controlled trials were identified to be effective if significant differences between groups across time were reported. Interventions of a pre-post study design were identified to be effective if significant changes across time were reported. Effect sizes were also examined and taken into account when

evaluating the effectiveness of the interventions. The benchmark criteria for effect sizes are 0.20 for a small effect, 0.50 for a medium effect, and 0.80 for a large effect (Cohen, 1992).

Results

Study Selection

The first database search (app-alone) identified 15,576 studies, following the removal of duplicates. Title and abstract screening deemed 15,544 studies ineligible for inclusion. In total, 32 full-text articles were screened for inclusion, with 23 studies excluded at this point (see Figure 1 for reasons). Forward and backward searching identified 1 additional study that was eligible for inclusion. A total of 10 app-alone studies were deemed relevant according to the predefined criteria and thus were included in this review (Figure 1).

The second database search (app online social networking) identified 4165 studies, after removing duplicates. Title and abstract screening identified 4151 ineligible studies. In total, 14 full-text articles were screened for inclusion, resulting in 10 studies being excluded (see Figure 2 for reasons). Screening of reference lists and forward searching identified 1 additional study that was eligible for inclusion. A total of 5 studies were deemed suitable to be included in this review (Figure 2).

Thus, the following review included a total of 15 studies. Of these, 10 studies used an app alone, and 5 studies incorporated an app in conjunction with an existing online social networking platform. These numbers of studies are similar to those of a recent comparative review (Nour, Yeung, Partridge, & Allman-Farinelli, 2017).

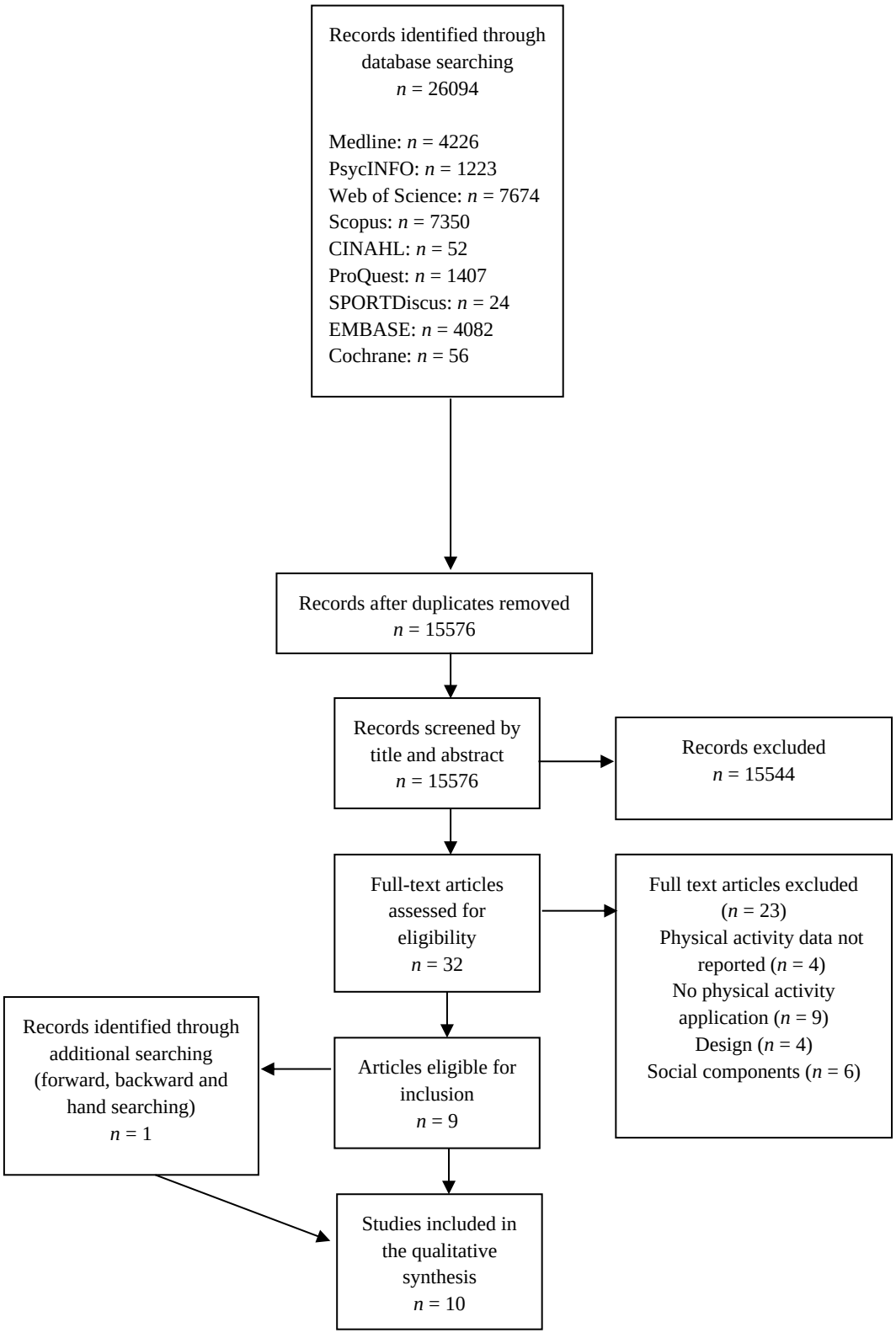

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart: App-alone search.

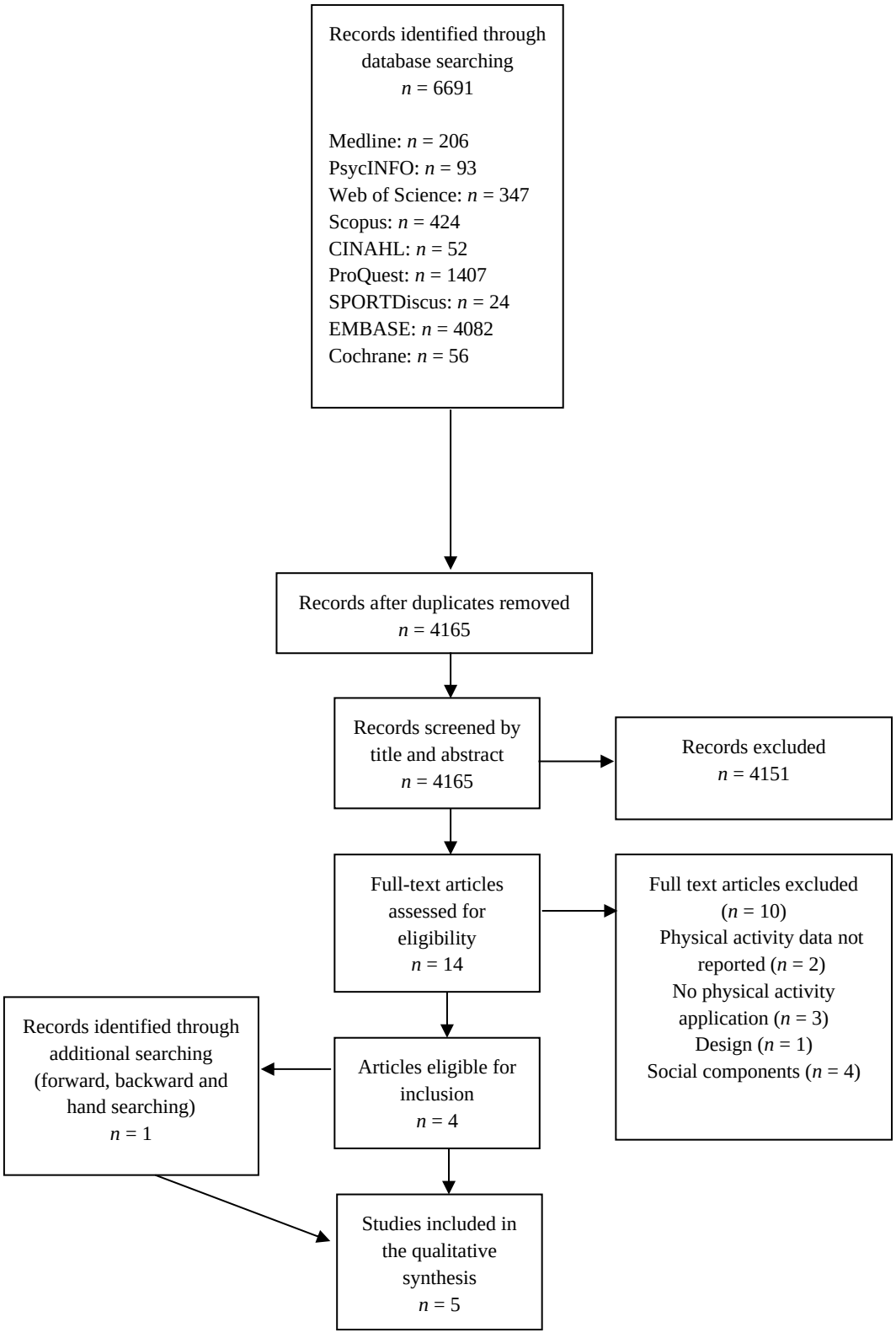

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart: App online social networking search.

Characteristics of Included Studies

The characteristics of the app-alone studies are tabulated in Appendix A and those of the app online social networking studies are tabulated in Appendix B. The app-alone and app online social networking studies were comparable in years of publication and the countries where the studies were conducted. However, the study designs differed such that the app-alone studies predominately utilised an experimental design (n = 7), whereas the app online social networking studies predominantly utilised within-subjects pre-post designs (n = 4). Across the seven app-alone studies that utilised an experimental design, the control groups received either a no intervention control (n = 1); minimal intervention (e.g., accelerometer or print materials; n = 5); or an app that differed slightly (fewer features; n = 1). By contrast, the one app online social networking study that included a control utilised a waitlisted control condition (Hurkmans et al., 2018). Among all included studies, two app online social networking studies (Hurkmans et al., 2018; Torquati, Kolbe-Alexander, Pavey, & Leveritt, 2018) aimed to modify physical activity in conjunction with dietary quality. Across the app-alone and app online social networking studies, a greater number of interventions utilised newly designed apps (n = 10) than commercially available apps (n = 5). The app-alone and app online social networking studies incorporated samples that were similar in size, age, and the predominance of female participants. The samples that were composed of women, were women who were healthy, overweight and obese, insufficiently active, or nurses. Although both the app-alone and app online social networking studies largely recruited from a specific population (n = 11), disparities were noted among the app-alone and app online social networking studies in relation to the populations recruited. Specifically, the app-alone interventions recruited samples that were sedentary (n = 3), low active (n = 3), obese or overweight (n = 2), in primary care (n = 1), pregnant (n = 1), or diagnosed with Type 2 diabetes (n = 1). Contrastingly, the app online social networking interventions targeted

samples that were nurses (*n* = 2), breast cancer survivors (*n* = 1), and obese or overweight (*n* = 1). The average intervention duration for app-alone studies ranged from 1 week (Arrogi et al., 2019) to 14 weeks (Korinek et al., 2018), comparable with the intervention durations of the app online social networking studies that ranged from 3 weeks (Foster, Linehan, Kirman, Lawson, & James, 2010) to 3 months (Torquati et al., 2018). One app-alone study incorporated a 3-month follow-up assessment (Simons et al., 2018), whereas two app online social networking studies incorporated follow-up assessments at 1 week postintervention (Pope, Lee, Zeng, Lee, & Gao, 2019) and 6 months postintervention (Torquati et al., 2018).

Among the app-alone and app online social networking studies, all apps targeted aerobic physical activity including light physical activity (*n* = 6), moderate physical activity (*n* = 2), moderate-to-vigorous physical activity (MVPA; *n* = 6), vigorous physical activity (*n* = 2), and daily steps (*n* = 9). The apps incorporated a diverse range of features targeted at encouraging physical activity, including monitoring or tracking of behaviour (apps with inbuilt accelerometry, *n* = 4; wearable activity tracker, *n* = 5), feedback (*n* = 7), information or education relating to physical activity (*n* = 4), goal setting (*n* = 5), and reinforcements (*n* = 4). Both the app-alone and app online social networking studies were underpinned by a diverse range of behaviour change theories, namely the Social Cognitive Theory, Self-determination Theory, Control Theory, Goal-Setting Theory, attitude-social influence self-efficacy model, the Behaviour Change Wheel, and the Theory of Reasoned Action.

Description of the Existing Social Networks

Among the app online social networking studies, all five incorporated Facebook as the existing online social networking platform; however, this platform was differentially utilised. In total, two studies provided participants with a link to a private Facebook group (Hurkmans et al., 2018; Torquati et al., 2018); and one study incorporated a public Facebook page that included educational tips related to physical activity and participants were

encouraged to comment and generate posts (Pope et al., 2019). Alternatively, in two studies, the app had the functionality to connect to Facebook, whereby participants could share their physical activity data and receive *likes* and comments (Al Ayubi, Parmanto, Branch, & Ding, 2014; Foster et al., 2010). The existing online social networks most often utilised features that facilitated social interaction (sharing physical activity posts, liking or commenting on others posts, and communicating with others; *n* = 5), social comparison (viewing posts of others' physical activity performance; *n* = 3), and competition (ranking table and group averages; *n* = 2).

Measures of Physical Activity and Additional Outcomes

Both the app-alone and app online social networking studies primarily measured physical activity objectively (*n* = 14), specifically by utilising an accelerometer (*n* = 8), pedometer (*n* = 3), Fitbit (*n* = 2) or inclinometer (*n* = 1). Among all included studies, two app-alone studies measured physical activity by self-report, specifically by using the International Physical Activity Questionnaire (IPAQ)-Long form (Simons et al., 2018) and IPAQ-Short form (Cowdery, Majeske, Frank, & Brown, 2015). Physical activity outcomes predominantly targeted for modification included light physical activity (*n* = 6), moderate physical activity (*n* = 2), MVPA (*n* = 6), vigorous physical activity (*n* = 2), daily steps (*n* = 9), or sedentary behaviour (*n* = 5). Across all studies, the underlying psychosocial outcomes related to physical activity (i.e., self-efficacy and exercise motivation) were assessed by four app-alone studies (Choi, hyeon Lee, Vittinghoff, & Fukuoka, 2016; Cowdery et al., 2015; Fanning et al., 2017; Simons et al., 2018) and two app online social networking studies (Pope et al., 2019; Torquati et al., 2018).

The Effectiveness of the Intervention

Table 1 provides a summary of the intervention effects on physical activity outcomes. Across all included studies, ten of the fifteen interventions effectively improved one or more

physical activity behaviours, including seven of the ten app-alone interventions and three of the five app online social networking interventions. Improvements were reported in either the intervention conditions relative to a control condition (n = 3) or over time (n = 7) for one or more physical activity behaviours. Specifically, the physical outcomes reported were increases in daily steps (n = 6); increases in light physical activity (n = 2); increases in MVPA (n = 3); and decreases in sedentary behaviour (n = 3). In total, five studies, three app-alone studies (Choi et al., 2016; Cowdery et al., 2015; Simons et al., 2018) and two app online social networking studies (Hurkmans et al., 2018; Torquati et al., 2018), did not find an intervention effect across groups (Choi et al., 2016; Cowdery et al., 2015; Hurkmans et al., 2018; Simons et al., 2018) or across time (Torquati et al., 2018) in any of the physical activity behaviours measured. Effect sizes varied widely among both the app-alone and app online social networking studies. Across the app-alone studies, effect sizes were small (n = 2) (Glynn et al., 2014; Walsh, Corbett, Hogan, Duggan, & McNamara, 2016), medium (n = 2) (Arrogi et al., 2019; Fanning et al., 2017), and large (n = 1) (Arrogi et al., 2019). Similarly, the distribution of effect sizes reported among the app online social networking studies ranged from small (n = 2) (Pope et al., 2019; Torquati et al., 2018) to medium (n = 2) (Foster et al., 2010; Pope et al., 2019) to large (n = 1) (Pope et al., 2019).

Table 1

Summary of intervention effects on physical activity outcomes

	Physical activity outcomes			Engagement
	Daily steps	Light, moderate, MVPA & vigorous PA	Sedentary behaviour	
App alone studies				
Arrogi et al. (2019)			++	
Bond et al. (2014)		+	+	
Choi et al. (2016)	-			x
Cowdery et al. (2015)		-		
Fanning et al. (2017)		+		x
Glynn et al. (2014)	++			
Korinek et al. (2018)	+			
Pellegrini et al. (2015)		+/-	-	✓
Simons et al. (2018)		-		x
Walsh et al. (2016)	++			
App online social networking studies				
Al Ayubi et al. (2014)	+			✓
Foster et al. (2010)	+			✓
Hurkmanns et al. (2018)		-		
Pope et al. (2019)	+	+	+	✓
Torquati, Kolbe-Alexander et al. (2018)	-	-	-	x

[a] Physical activity behaviour; +: significant within-group improvement in outcome; ++: significant between-group improvement in outcome; -: no improvement in outcome; +/-: mixed results; engagement; ✓: favourable (high) engagement; x : unfavourable (low) engagement.
[b] PA*:* Physical activity
[c] MVPA: Moderate-to-vigorous physical activity

Table 2 provides a summary of the intervention effects on psychosocial outcomes. The app-alone and app online social networking studies overall reported mixed results in relation to psychosocial outcomes associated with physical activity. Specifically, two app-alone studies (Cowdery et al., 2015; Simons et al., 2018) and one app online social networking study (Torquati et al., 2018) revealed no significant intervention effects on any of the assessed psychosocial outcomes. In total, two app-alone studies reported significant decreases in perceptions of barriers to exercising in the intervention condition; however, not in the alternative outcomes assessed (e.g., perceived social support and self-efficacy) (Choi et

al., 2016; Fanning et al., 2017). Contrastingly, one app online social networking study reported improvements over time in all psychosocial outcomes assessed (e.g., social support, physical activity self-efficacy, and enjoyment) (Pope et al., 2019).

Table 2

Summary of intervention effects on psychosocial outcomes

					Psychosocial outcomes			
	Social support	Self-efficacy	PA motivation	Barriers to PA	PA enjoyment	Outcome expectations	Perceived benefits of PA	Perceived PA competency
App alone studies								
Arrogi et al. (2019)								
Bond et al. (2014)								
Choi et al. (2016)	-	-		++				
Cowdery et al. (2015)			-		-			-
Fanning et al. (2017)		-		+		-		
Glynn et al. (2014)								
Korinek et al. (2018)								
Pellegrini et al. (2015)								
Simons et al. (2018)	-	-		-			-	
Walsh et al. (2016)								
App online social networking studies								
Al Ayubi et al. (2014)								
Foster et al. (2010)								
Hurkmanns et al. (2018)								
Pope et al. (2019)	+	+			+			
Torquati, Kolbe-Alexander et al. (2018)	-	-						

[a] Psychosocial outcomes; +: significant within-group improvement in outcome; ++: significant between-group improvement in outcome; -: no improvement in outcome
[b] PA*:* Physical activity

Measures of Engagement

Notably, only four of the ten app-alone studies (40%) reported on app usage, whereas 80% (n = 4) of the app online social networking studies assessed engagement with intervention materials (app and online social network). Among the studies that assessed app

engagement, objective measures were primarily utilised (*n* = 6). This included the use of Google Analytics to monitor app logins and duration of use (*n* = 2), the functionality of the app to record logins (*n* = 1) or days and minutes of use (*n* = 2), or monitoring of engagement with app content (e.g., reading or responding to automated messages and logging in activity diary; *n* = 2). Self-report measures of app engagement were also utilised in two app online social networking studies (Pope et al., 2019; Torquati et al., 2018). This included questionnaires whereby participants were asked to report frequency and duration of app use or engagement with app content (e.g., willingness to use app and follow instructions). All studies that measured app engagement objectively (*n* = 6), monitored app usage over the duration of the intervention period. Conversely, among the two studies that utilised self-report measures, the questionnaires were completed at two time points: at mid and postintervention (Pope et al., 2019) and at postintervention and 6-month follow-up (Torquati et al., 2018). Among the app online social networking studies, two reported engagement with the existing online social network, such that the number of Facebook posts generated and posts viewed was monitored (Pope et al., 2019; Torquati et al., 2018).

Engagement with the Intervention

Among the four app-alone studies that assessed engagement with the app, one reported that, on average, the app was used on 21 days for a cumulative total of 7.6 hours, over a 1-month intervention period (Pellegrini et al., 2015). The other three studies reported a notable decline in app engagement (Choi et al., 2016; Fanning et al., 2017; Simons et al., 2018). Specifically, decreases were reported in the frequency and duration of app usage and engagement with app content (logging physical activity and reading or responding to messages) over 9-week (Simons et al., 2018) and 12-week intervention periods (Choi et al., 2016; Fanning et al., 2017). Among the app online social networking studies, a single study reported limited engagement with the intervention materials over a 3-month intervention

period, reporting that 68.4% of participants used the app less than once a month or never and 47.5% of participants engaged with the Facebook page on only one occasion per week (Torquati et al., 2018). Conversely, two reported increases in minutes of app usage following the provision of access to the existing online social network (Al Ayubi et al., 2014; Foster et al., 2010), and one reported sustained engagement with intervention materials (app and Facebook page) (Pope et al., 2019).

Comparison of Effective and Ineffective Interventions

As can be seen in Table 1, across all included studies, seven of the ten app-alone interventions (70%) and three of the five app online social networking interventions (60%) were effective in improving one or more physical activity behaviours, as identified by *P* values and/or effect sizes. Among the effective interventions, the intervention durations were relatively short, ranging from 1 week (Arrogi et al., 2019) to 14 weeks (Korinek et al., 2018). In comparison, the ineffective interventions typically incorporated longer intervention durations, ranging from 9 weeks (Simons et al., 2018) to 3 months (Torquati et al., 2018). Notably, six of the ten (60%) effective interventions recruited low-active (n = 2) (Fanning et al., 2017; Korinek et al., 2018) or sedentary participants (n = 2) (Arrogi et al., 2019; Pellegrini et al., 2015), or documented that participants engaged in low levels of baseline physical activity (n = 2) (Bond et al., 2014; Walsh et al., 2016). By contrast, only two of the five (40%) ineffective interventions recruited low-active (n = 1) (Simons et al., 2018) or sedentary participants (n = 1) (Choi et al., 2016). The effective interventions all exclusively targeted physical activity behaviours. The two app online social networking interventions that were not effective (Hurkmans et al., 2018; Torquati et al., 2018) both targeted the modification of physical activity in conjunction with diet quality. Across all included studies, objective measures of physical activity were predominately utilised (n = 14), and the type of objective measure used (e.g., accelerometer) was comparable among the effective and

ineffective interventions. However, two of the five ineffective interventions utilised self-report measures to assess the physical activity behaviours (Cowdery et al., 2015; Simons et al., 2018). Both the effective (n = 6) and ineffective (n = 4) interventions were largely underpinned by behaviour change theories. Among the ten effective studies, seven (70%) used newly designed apps and three (30%) used commercially available apps. Among the five ineffective studies, three (60%) used newly designed apps and two (40%) used a commercially designed app.

In total, two of the effective interventions (Fanning et al., 2017; Pope et al., 2019) assessed psychosocial outcomes, and mixed findings were reported. Specifically, the app-alone study that incorporated a newly designed app reported no changes in physical activity self-efficacy or physical activity outcome expectancies but identified a decrease in perceptions of barriers to exercising (Fanning et al., 2017). In contrast, the app online social networking study that incorporated a commercially available app reported increases in physical activity self-efficacy, physical activity enjoyment, and social support (Pope et al., 2019). In total, four of the ineffective studies assessed psychosocial outcomes (Choi et al., 2016; Cowdery et al., 2015; Simons et al., 2018; Torquati et al., 2018), and although one study identified a decrease in the lack of energy as a barrier to exercising (Choi et al., 2016), no changes were reported in any of the alternative outcomes assessed, including social support, physical activity self-efficacy, physical activity enjoyment, physical activity motivation, perceived competency for exercising regularly, and perceived benefits to exercising.

Among the effective studies, one app-alone study (Fanning et al., 2017) and all app online social networking studies (n = 3) (Al Ayubi et al., 2014; Foster et al., 2010; Pope et al., 2019) reported on app engagement. The app-alone study reported a decline in app usage over the 12-week intervention period (Fanning et al., 2017). In contrast, in the app online

social networking studies, higher app usage following the provision of access to the online social networking functionalities (Al Ayubi et al., 2014; Foster et al., 2010) and sustained engagement with intervention materials (app and Facebook page) were reported (Pope et al., 2019). Among the ineffective studies, three of the five studies reported on intervention engagement (Choi et al., 2016; Simons et al., 2018; Torquati et al., 2018). Of these studies, all reported unfavourable intervention engagement, specifically declines in app engagement during a 9-week (Simons et al., 2018) and 12-week intervention period (Choi et al., 2016), and low engagement with intervention materials (app and Facebook group) (Torquati et al., 2018). Additionally, among the effective app online social networking interventions, the existing social networks utilised were a public Facebook page (n = 1) (Pope et al., 2019) or a physical activity app that incorporated functionalities to connect with Facebook (n = 2) (Al Ayubi et al., 2014; Foster et al., 2010). Among the two ineffective app online social networking interventions, both incorporated a private Facebook group as the existing online social network (Hurkmans et al., 2018; Torquati et al., 2018).

Reporting of Methodological Characteristics

The reported methodological characteristics were examined to generate a methodological risk of bias score. Scores ranged from 9.5 (out of 20) to 20.5 (out of 25) in the app-alone studies and from 8.5 (out of 20) to 18 (out of 25) in the app online social networking studies. The app-alone and app online social networking studies all fulfilled the checklist criteria for scientific background and a detailed description of the intervention. Among the randomised controlled trials (n = 8), few adequately reported on the allocation concealment mechanisms (n = 3) or blinding (n = 3); however, most did report on randomisation procedures (n = 7). Notably, both the app-alone and app online social networking studies rarely fulfilled the criterion detailing how the sample size was calculated (n = 8) or appropriately reported on the study outcomes (effect sizes; n = 7).

Discussion

Principal Findings

This review examined the influence of existing online social networking platforms on the engagement with, and effectiveness of, mobile apps that target physical activity. Specifically, to isolate the influence of existing online social networking platforms, the review provided a comparison between interventions that incorporated physical activity apps in conjunction with and without existing online social networking platforms.

The review identified that physical activity apps show promise in their capacity to improve physical activity behaviours. Of the included studies, ten of the fifteen interventions effectively improved one or more physical activity behaviours. Specifically, seven of the ten app-alone studies and three of the five app online social networking studies reported improvements. At a surface level, these findings indicate that the app online social networking interventions may be no more effective than the app-alone interventions. However, this may be attributed to methodological disparities between the app-alone and app online social networking interventions rather than the presence of online social networking *per se*. Specifically, heterogeneity in the recruited samples may have influenced physical activity outcomes and thus must be considered in the formation of accurate conclusions regarding intervention effectiveness. This is highlighted in the comparison of two app-alone (Bond et al., 2014; Korinek et al., 2018) and an app online social networking intervention (Hurkmans et al., 2018) that all targeted the modification of physical activity in overweight or obese individuals. The two app-alone interventions (Bond et al., 2014; Korinek et al., 2018) both improved physical activity levels, whereas the app online social networking study did not (Hurkmans et al., 2018). However, both app-alone studies (Bond et al., 2014; Korinek et al., 2018) reported low baseline levels of physical activity, which may have influenced intervention outcomes. Furthermore, the differences in the samples recruited may also be

responsible for overall differences in intervention effectiveness between the app-alone and app online social networking studies. Specifically, 80% (*n* = 8) of the app-alone interventions recruited low-active (*n* = 3) or sedentary participants (*n* = 3) or reported that participants engaged in low levels of physical activity at baseline (*n* = 2). Of these interventions, 75% (*n* = 6) reported improvements in physical activity behaviours. This is consistent with previous literature documenting that physical activity interventions demonstrate greater effectiveness among low-active individuals, as there is a larger potential for improvement in behaviour (Lubans, Morgan, & Tudor-Locke, 2009). In contrast, none of the app online social networking interventions incorporated recruitment criteria regarding sedentary or physical activity behaviours or reported low baseline levels of physical activity. Thus, the disparity among the samples may have influenced intervention outcomes, limiting the formation of appropriate conclusions regarding the influence of existing online social networking platforms on intervention effectiveness. Future research is needed to evaluate the effectiveness of apps in conjunction with online social networks in low-active or sedentary populations.

The comparability of intervention engagement between the app-alone and the app online social networking interventions is also somewhat limited by the lack of reporting on engagement in the app-alone studies. This is consistent with existing reviews that have documented a lack of assessment of engagement in interventions targeting health behaviours (Schoeppe et al., 2016). This presents a shortcoming of research to date, such that the previously limited assessment of engagement has hindered the identification of intervention components that may be associated with engagement. This review identified clear differences in the levels of engagement reported among the app-alone and app online social networking studies. The app-alone studies that reported on patterns of engagement identified declines in app engagement over 9-week (Simons et al., 2018) and 12-week intervention periods (Choi et

al., 2016; Fanning et al., 2017). Of these studies, one reported improvement in physical activity behaviours (Fanning et al., 2017), whereas the other two did not (Choi et al., 2016; Simons et al., 2018). Across the app online social networking studies, one study reported low engagement with intervention materials (app and Facebook group), and notably no improvement in physical activity outcomes (Torquati et al., 2018). In contrast, all other app online social networking studies reported increases in engagement following the provision of access to the existing online social networking platform (Al Ayubi et al., 2014; Foster et al., 2010) and sustained engagement with intervention materials (app and Facebook page) (Pope et al., 2019). Among these studies, all reported improvements in physical activity behaviours (Al Ayubi et al., 2014; Foster et al., 2010; Pope et al., 2019), in line with previous evidence linking engagement with intervention effectiveness (Poirier & Cobb, 2012; Schoeppe et al., 2016). Thus, the app-alone studies demonstrated the typically observed decline in app engagement (Choi et al., 2016; Fanning et al., 2017; Simons et al., 2018), whereas the app online social networking studies showed increased and sustained intervention engagement (Al Ayubi et al., 2014; Foster et al., 2010; Pope et al., 2019). This review provides preliminary evidence that existing online social networking platforms may be an important component in increasing engagement with physical activity interventions.

The existing online social networking platform incorporated into all the app online social networking interventions was Facebook, including either a public Facebook page (Pope et al., 2019), a private Facebook group (Hurkmans et al., 2018; Torquati et al., 2018), or a physical activity app that had the functionality to connect to Facebook (Al Ayubi et al., 2014; Foster et al., 2010). The existing online social networks utilised a diverse range of features that primarily facilitated social interaction, social comparison, and competition. However, the heterogeneity in the features utilised, and the predominance of studies that incorporated several different features, limited the capacity to ascertain the association

between specific features of online social networking and app engagement. Interestingly, the findings indicated that the differential use of the Facebook platform may have influenced intervention effectiveness. The interventions incorporating a private Facebook group did not report improvements in physical activity behaviours (Hurkmans et al., 2018; Torquati et al., 2018). Of these interventions, one study (Torquati et al., 2018) reported on intervention engagement and psychosocial constructs, identifying low intervention engagement, and no changes in social support or self-efficacy. Contrastingly, the interventions that incorporated a Facebook page (Pope et al., 2019), or an app that connected with Facebook (Al Ayubi et al., 2014; Foster et al., 2010) showed improvements in physical activity behaviours and resulted in increased and sustained engagement. Additionally, increases were reported in social support, self-efficacy, and physical activity enjoyment in one of these studies (Pope et al., 2019). Importantly, these are all psychosocial constructs associated with facilitating physical activity behaviours (Trost, Owen, Bauman, Sallis, & Brown, 2002), intervention engagement (Perski et al., 2017; Poirier & Cobb, 2012), and sustained behaviour change (Courneya et al., 2000). Notably, among the interventions that produced favourable outcomes (Al Ayubi et al., 2014; Foster et al., 2010; Pope et al., 2019), participants' existing networks were leveraged via apps that connected with Facebook (Al Ayubi et al., 2014; Foster et al., 2010), or a Facebook page (Pope et al., 2019). Contrastingly, the interventions that produced unfavourable outcomes (Hurkmans et al., 2018; Torquati et al., 2018) incorporated private Facebook groups that generated an artificial online social network, such that participants were required to create connections with unknown others. This indicates that network dynamics may be an important underlying determinant of the influence of online social networks on intervention outcomes.

Implications for Future Research

This review suggests that the way in which online social networking platforms are utilised must be considered in the development of interventions as it has important implications for intervention effectiveness. This highlights a gap in the literature, such that little guidance exists in relation to optimally harnessing online social networking platforms in behaviour change interventions. Future research must endeavour to identify specific features of online social networking platforms that are associated with intervention engagement, to ascertain how best to incorporate online social networking into health interventions. However, this will require a greater understanding of the mechanisms (e.g., social support) underlying the influence of online social networking on health behaviours, to elucidate how best to leverage specific features of online social networking platforms in health interventions. In addition, online social networking is evolving rapidly, and thus, an understanding of the underlying mechanisms will be advantageous in identifying how to optimally leverage a diverse range of social networking platforms in future interventions.

The present review further ascertained disparities among the designs and quality of app-alone and app online social networking studies. The app-alone interventions were predominately randomised controlled trials; by contrast, the app online social networking studies were largely pre-post within-subjects designs. Future research must endeavour to utilise study designs of a higher standard to increase the quality of evidence pertaining to the effectiveness of interventions incorporating physical activity apps in conjunction with online social networking. More specifically, Vandelanotte and Maher (2015) suggest that ecologically valid trials that emulate the real-world conditions of online social networks are necessary to establish the effectiveness and reach of such networks. Furthermore, the app-alone and app online social networking studies incorporated predominately short intervention durations, and across all studies in the review, only three included follow-up assessments, at

1-week postintervention (Pope et al., 2019), 3 months (Simons et al., 2018), and 6 months postintervention (Torquati et al., 2018). The dearth of evidence regarding the long-term efficacy of mobile apps is frequently documented as an important shortcoming. Evaluating the long-term effectiveness of mobile apps is imperative, as sustained engagement in physical activity behaviour is required to attain the associated health benefits (Warburton et al., 2006).

The review identified several features of the interventions that may be important in guiding the design of future app-based interventions. Specifically, interventions that were effective targeted exclusively the modification of physical activity behaviours. This is consistent with a systematic review of 27 app-based health interventions indicating that interventions that target a single behaviour are more effective than those that target multiple behaviours (e.g., physical activity and dietary behaviour) (Schoeppe et al., 2016). Across health interventions more broadly (e.g., face-to-face, web-based), there is some evidence to suggest that interventions that target behaviours simultaneously or sequentially are equally effective (James et al., 2016). Our research along with Schoeppe et al. (2016) does, however, indicate that the efficacy of app-based interventions may be optimised by targeting the modification of one health behaviour. Furthermore, the interventions that were effective incorporated objective measures of physical activity. Interestingly, the two studies that incorporated a self-report measure of physical activity did not report an increase in physical activity over intervention periods of 9 (Simons et al., 2018) and 12 weeks (Cowdery et al., 2015). It is possible that self-report measures as opposed to objective measures such as accelerometers afford lower sensitivity to detect changes in physical activity behaviours over short intervention periods (Shephard, 2003). Indeed, a previous review has demonstrated that 69% of studies that incorporated self-report measures, as opposed to 20% of studies that measured physical activity objectively, found no effect on physical activity (Covolo et al., 2017). In addition, in this review, comparatively, there was no difference in the effectiveness

of interventions that used a newly designed app as opposed to a commercially available app. Despite this, the interventions largely utilised newly designed apps, and this could, in part, be attributed to the control afforded to researches in relation to the settings, features and functionalities of such apps. Nevertheless, this is problematic as commercially available apps are ubiquitous and highly accessible to the general public; however, evidence of their effectiveness is lacking (Bondaronek et al., 2018; Conroy et al., 2014; Cowan et al., 2013). Thus, future research should evaluate the effectiveness of commercially available physical activity mobile apps.

Overall, the mobile apps were effective in increasing physical activity in a diverse range of population samples, including inactive (Fanning et al., 2017; Korinek et al., 2018), sedentary (Arrogi et al., 2019; Pellegrini et al., 2015), obese or overweight individuals (Bond et al., 2014; Korinek et al., 2018), breast cancer survivors (Pope et al., 2019), and individuals diagnosed with Type 2 diabetes (Pellegrini et al., 2015). However, all studies exclusively targeted adults, ranging from 20 (Walsh et al., 2016) to 53 years (Pellegrini et al., 2015). Thus, future research must endeavour to evaluate the applicability of physical activity mobile apps in conjunction with existing online social networks in alternative age groups, in particular among adolescents, a highly inactive population subgroup (World Health Organisation, 2018), and among the highest users of existing online social networking platforms (Anderson, Jiang, & Pew Research Center, 2018). This will ensure that mobile apps are an appropriate medium to disseminate physical activity interventions that are scalable, owing to their applicability to the population broadly.

This review also has important implications for guiding the development of an appropriate theoretical foundation to inform future physical activity mobile apps. The included interventions incorporated mobile apps predominately underpinned by behaviour change theory. This suggests that there was no association between mobile app effectiveness

and the utilisation of any one particular theory. Additionally, across the included studies a diverse range of behaviour change theories were utilised, limiting the formation of conclusions regarding the most effective theory to guide the development of physical activity mobile apps. This is consistent with previous research examining the content of physical activity mobile apps that has documented challenges ascertaining the theory or combination of theories associated with physical activity mobile app effectiveness (Stuckey et al., 2017).

The physical activity apps examined in this review incorporated a diverse range of features. The most common among these were monitoring or tracking of behaviour, feedback, information or education related to physical activity, goal setting, and providing reinforcements (e.g., points). Much of the previous research that has examined the content of physical activity apps has utilised a taxonomy developed by Abraham and Michie (2008) that functions to isolate the presence of behaviour change techniques common to many behaviour change theories. This research has identified that feedback, self-monitoring, and goal setting are features frequently integrated into apps, in line with findings by this review (Bondaronek et al., 2018; Middelweerd, Mollee, van der Wal, Brug, & Te Velde, 2014; Simões et al., 2018). Notably, Michie, Abraham, Whittington, McAteer and Gupta (2009) highlight that these features are also commonly associated with effectively modifying physical activity behaviour. This may have underpinned the capacity of the majority of the apps in the current review to improve physical activity behaviour. However, the specific number or combination of features that may have a greater influence on the effectiveness of physical activity apps is currently unknown, and thus requires future examination.

Limitations

To our knowledge, this is the first review to isolate the influence of existing online social networking platforms by providing a comparison between interventions that incorporate mobile physical activity apps in conjunction with and without existing online

social networking platforms. Despite the novel nature of this review, several limitations must be noted. First, to date, there are only a small number of studies that have incorporated physical activity apps in conjunction with an existing online social networking platform. Additionally, owing to the heterogeneity of the identified studies in relation to the target population, intervention, study design, and outcomes measured, the results could not be validly pooled, precluding the ability to conduct a meta-analysis, and thus, form definitive conclusions regarding the influence of online social networks. There is a need for future research to conduct robust multi-arm trials to strengthen the evidence pertaining to the additive value of such networks. Second, all interventions incorporated apps that targeted aerobic activity, and thus, the findings may not generalise to apps aimed at other types of physical activity such as strength training. Future research should endeavour to examine apps targeted at all forms of physical activity. Third, among the included studies the methodological risk of bias varied, with some studies receiving low scores, and thus, caution should be taken when interpreting their findings. For example, few studies reported a power calculation, and across the randomised controlled trials methodological reporting was often inadequate (e.g., allocation concealment mechanisms, blinding). Finally, there is a possibility of publication bias as the search did not incorporate gray literature or non-English publications.

Conclusions

In conclusion, the unprecedented growth in physical activity apps presents an innovative medium to disseminate scalable interventions to increase levels of physical activity worldwide. However, previous literature has consistently documented that the effectiveness of mobile apps is limited by low levels of engagement. The popularity, reach, and engagement afforded by existing online social networking platforms provides an unparalleled opportunity to serve as an adjunct to mobile apps to augment engagement, and

ultimately effectiveness. Thus, this review aimed to provide insight into the influence of existing online social networks by providing a comparison between interventions that incorporated mobile apps in conjunction with and without existing online social networking platforms. Both the interventions incorporating physical activity apps in conjunction with and without existing online social networking platforms demonstrated effectiveness in improving physical activity behaviours. Notably, however, interventions that incorporated existing online social networking platforms achieved higher levels of engagement than those that did not. This provides preliminary evidence that existing online social networking platforms may be fundamental in overcoming the previously documented low engagement associated with physical activity mobile apps. This is of particular importance as greater app engagement is associated with increased exposure to intervention content, and ultimately an enhanced capacity of the app to effectively improve physical activity behaviour. Thus, existing online social networking platforms must be further evaluated by conducting rigorously designed randomised controlled trials. Importantly, future research must endeavour to provide a greater understanding of the mechanisms underlying the influence of existing social networking platforms on physical activity behaviours, to ascertain how best to leverage specific features of these platforms. This review makes an important contribution to guiding future research, by providing an initial insight into mobile apps and existing online social networking platforms, imperative to improving the development of interventions targeted at increasing physical activity levels.

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CHAPTER 3: STUDY 2

Associations Between Commercial App Use and Physical Activity: Cross-Sectional Study

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Abstract

Background: In today's society, commercial physical activity apps (e.g., Fitbit and Strava) are ubiquitous and hold considerable potential to increase physical activity behaviour. Many commercial physical activity apps incorporate social components, in particular app-specific communities (allowing users to interact with other app users) or the capacity to facilitate connections to existing social networking platforms (e.g., Facebook or Instagram). There is a growing need to gain greater insights into whether commercial physical activity apps and specific components of these apps (social components) are beneficial in facilitating physical activity. **Objective:** This study aimed to examine the relationship between the use of commercial physical activity apps and engagement in physical activity. The social components of commercial physical activity apps (app-specific communities and existing social networking platforms) were also explored. This involved isolating specific features (e.g., sharing, providing and receiving encouragement, comparisons, and competitions) of app-specific communities and existing social networking platforms that were most valuable in facilitating physical activity. **Methods:** A cross-sectional web-based survey was conducted. Participants were 1432 adults (mean age 34.1 years, 88.0% female) who completed measures assessing physical activity, the use of commercial physical activity apps, and engagement with app-specific communities and existing social networking platforms. **Results:** Overall, 53.1% of the sample reported engaging with a commercial physical activity app. The most commonly used apps were Fitbit (22.5%), Strava (17.1%), and Garmin (13.4%). The use of physical activity apps was significantly associated with physical activity. Notably, the use of app-specific communities and existing social networking platforms facilitated significantly greater engagement in physical activity. The features of app-specific communities that were most beneficial in promoting engagement in physical activity were providing encouragement to a partner, receiving encouragement from close friends and

family, and engaging in competitions with members of public app-specific communities. In relation to existing social networking platforms, sharing physical activity posts predicted engagement in physical activity. **Conclusions:** The findings indicate that app-specific communities and existing social networking platforms are components of apps that are fundamental in facilitating physical activity. They further suggest that commercial physical activity apps afford high population level reach and hold great potential to promote engagement in physical activity, an important public health consideration.

Introduction

Physical activity confers many health benefits, including a reduced risk of cardiovascular disease, hypertension, osteoporosis, diabetes mellitus, obesity, mental illness, and premature mortality (Barbour, Edenfield, & Blumenthal, 2007; Lee et al., 2012; Warburton, Nicol, & Bredin, 2006). Despite this, globally, 1.4 billion adults (28%) are not meeting physical activity guidelines (150 min of moderate to vigorous physical activity per week), a figure that continues to rise (Guthold, Stevens, Riley, & Bull, 2018). This highlights the need to develop scalable interventions to increase physical activity.

Physical activity mobile apps present an innovative approach to promote engagement in physical activity due to their widespread reach, accessibility, and convenience. Recently, there has been exponential growth in the availability of commercial physical activity apps (e.g., Fitbit, Strava, and Garmin) (Aitken, Clancy, Nass, & IQVIA, 2017). However, much of the previous research examining physical activity apps has focused on apps developed by researchers as opposed to commercially available apps (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018; Petersen, Prichard, & Kemps, 2019). This presents a shortcoming of research to date, such that despite the accessibility and ubiquity of commercial apps, there is limited literature exploring their use and influence on physical activity. This indicates the need to gain greater insight into the use of commercial apps to ascertain their capacity to increase levels of physical activity, and thus, improve public health.

A growing body of research examining the content of commercial apps has identified that social features are an increasingly ubiquitous component (Bondaronek et al., 2018; Conroy, Yang, & Maher, 2014; Mollee, Middelweerd, Kurvers, & Klein, 2017). That is, many commercial apps incorporate app-specific communities, allowing users to interact with other app users by sharing physical activity data, receiving or providing encouragement (e.g., likes and comments), and engaging in competitions or comparisons (Mollee et al., 2017).

However, to date, there has been little examination of app-specific communities, and, in particular, the association between engagement with the features of these communities (e.g., sharing and competitions) and physical activity. Insights into app-specific communities is important to ascertain their value in promoting engagement in physical activity and crucial for the development of future physical activity interventions.

Content analyses of commercial apps have identified that many physical activity apps also have the capacity to facilitate connections to existing social networking platforms such as Facebook or Instagram (Mollee et al., 2017). This has been suggested to be an important component of an app, given that a recent review (Petersen et al., 2019) identified that the use of existing social networking platforms in conjunction with apps enhances engagement. However, the review (Petersen et al., 2019) also documented that this research area is in its infancy, and there is a need to gain greater insights into how to optimally harness existing social networking platforms in conjunction with physical activity apps. This requires identifying the features of existing social networking platforms (e.g., social interaction and comparisons) that are associated with app engagement, and thus, physical activity.

Objectives

To our knowledge, no previous study has comprehensively examined commercial physical activity apps and specifically, how the social components of these apps (app-specific communities or existing social networking platforms) may be associated with physical activity. This is important given the increasing prevalence of commercial physical activity apps together with the need to isolate components of apps that are linked to physical activity engagement. Thus, the first aim of this study was to gain a comprehensive understanding of the use of commercial physical activity apps and their relationship with physical activity. The second aim was to explore the value of app-specific communities and existing social networking platforms in facilitating physical activity. More specifically, we sought to

ascertain the features of app-specific communities and existing social networking platforms that were used and how these were associated with frequency of app use and engagement in physical activity.

Methods

Study Design and Participants

A web-based cross-sectional survey was conducted. Participants were recruited via the Discipline of Psychology's web-based research participation system (4.2% of sample), paid Facebook advertising, and free advertisements placed on social networking platforms (e.g., Facebook, Instagram, and Twitter) for a study on Physical Activity and Online Social Networking. Ethical approval was obtained from the University Social and Behavioural Research Ethics Committee (protocol no. 8232). All participants provided informed consent electronically. Participants were adults, ≥18 years, and proficient in English.

Procedure

Participants completed a web-based survey through the Qualtrics platform between February and April 2019. The survey (Appendix C) took approximately 30 min to complete and incorporated the measures listed below in the order of presentation, in addition to assessments of psychological constructs (i.e., social support, self-efficacy and motivation) reported elsewhere (Study 3; Chapter 4). As a token of appreciation, participants could enter a raffle to win 1 of 5 AUD $25 shopping gift vouchers.

Measures

Demographics. Participants were invited to report their age, gender identity, and ethnicity.

Regular structured physical activity. Regular structured physical activity was assessed following the methods of Prichard and Tiggemann (2008). Participants were invited to self-report the type, duration, and frequency of structured physical activity or sports they

generally engaged in on a weekly basis. The total number of minutes of physical activity engaged in per week was then calculated by multiplying each activity's frequency by its duration. Separate physical activity totals were calculated according to the type of physical activity listed, specifically individual physical activities (e.g., walking or running), gym-based activities (e.g., gym classes), or sports-based activities (e.g., netball or football).

Current physical activity app use. Participants were asked to self-report their current use of physical activity apps, defined as apps that have the capacity to track or monitor physical activity (e.g., steps or distance) or provide guided training or workouts. In particular, participants were asked to self-report using an open-ended response format, the name of the physical activity app they were currently using most frequently (main physical activity app, e.g., Strava), the physical activity or sport they were using the app for, and their level of engagement with the app (number of times used per week). The apps were categorised according to their capabilities, including tracking, providing guided workouts, tracking plus providing guided workouts, or other (e.g., scheduling gym classes or immersive games). The types of physical activity the apps were used for were classified as all daily activities, individual activities (e.g., running, cycling, or walking), group-based activities (e.g., netball, soccer, or football), gym-based activities (e.g., fitness classes or personal training), or a combination of different activities (individual, group-based and gym-based activities).

Engagement with app-specific communities. In relation to the main physical activity app participants were currently using, they were asked to self-report their engagement with the features of the app-specific community. This included specifying how frequently on a 6-point Likert scale ranging from 0 (*never*) to 5 (*very often*) they engaged with specific features of the app community, such as sharing physical activity posts, liking and/or providing positive comments on others' posts, receiving likes and/or positive

comments, comparing their physical activity performance with others, and engaging in competitions. Furthermore, participants were asked to indicate the frequency that they engaged with the aforementioned features with specific members of their app community, including partners, family, close friends, peers, public app-specific community members, and work colleagues. Example items include *Within the main physical activity app you are currently using, how often do you share posts relating to your physical activity performance with a partner*? and *Within the main physical activity app you are currently using, how often do you Like/Kudos/Cheer and/or provide positive comments on physical activity posts from close friends*? As the networks within each feature were highly correlated ($\alpha = .74$), a composite score was calculated for the use of each specific feature of the app community (e.g., sharing) across the different networks (e.g., peers and family) while also examining the independent influence of engaging with specific networks in relation to each feature.

Participants who specified that the main physical activity app they were using incorporated an app-specific community but reported that they did not engage with it were provided with an open-ended question to determine the underlying rationale for this. Preliminary themes were established by the first author, and the responses were subsequently categorised by two independent coders.

Engagement with existing social networking platforms. Participants were also asked to self-report their physical activity-related use of existing social networking platforms on measures developed for this study. Specifically, participants were asked to specify on a 6-point Likert scale how frequently (from *never* = 0 to *very often* = 5) they share physical activity posts, like and/or provide positive comments on others' posts, receive likes and/or positive comments, and compare their physical activity performance with others' physical activity posts on Facebook, Instagram, and Twitter (plus the option to specify other platform(s)). Example items included *How often do you share physical activity posts on the following social networking platforms? and How often do you like and/or provide positive*

comments on physical activity posts from other people on the following social networking platforms? A composite score was calculated for the use of each specific feature (e.g., sharing) across the different social networking platforms (e.g., Facebook and Instagram).

Statistical Analysis

Data were analysed using Statistical Package for the Social Sciences version 25 (IBM, Corp). Significance for all analyses was set at $P < .05$ (2-tailed). A power analysis using the statistical software G-Power demonstrated that the sample size was adequate to detect a medium sized effect with 90% power and alpha level of 0.05 for all analyses (Faul et al., 2009).

Missing data were handled using pairwise deletion as there was minimal missing data. Overall, the study variables (with the exception of app engagement) did not deviate substantially from normality based on skewness, kurtosis, or histogram examination. More specifically, skewness values ranged from 0.10 to 1.6, and kurtosis values ranged from 0.04 to 2.1. Therefore, parametric tests were used for all analyses, except those that included the variable app engagement for which a nonparametric test (Kruskal-Wallis test) was used.

Descriptive statistics were used to generate demographic information. A series of independent samples *t* tests and chi-square analyses were conducted to determine differences between app users and nonusers in age, gender identity, ethnicity, and minutes of physical activity per week. Chi-square analyses were used to identify differences in app use (i.e., the most commonly used apps, the capabilities of the apps used, and the activity app is used for) based on demographics (age and gender identity). A Kruskal-Wallis test with pairwise comparisons using the Dunn-Bonferroni correction was conducted to examine the relationship between app engagement (frequency of app use per week) and physical activity.

Kruskal-Wallis tests were also conducted to examine the relationships between the use of specific features of app-specific communities and app engagement among app users. In addition, one-way analyses of variance were performed to determine differences in engagement with features of app-specific communities based on age, capabilities of the app used, and activity the app was used for, but not for gender identity (because of the small proportion of men). The aforementioned analyses were repeated using specific features of existing social networking platforms. Independent samples *t* tests and chi-square analyses were also used to determine differences between users and nonusers of the app-specific communities and existing social networking platforms.

Finally, a multiple linear regression was conducted to explore the predictors of physical activity among app users. The regression model incorporated the frequency of app usage and all features of both app-specific communities (including specific networks) and existing social networking platforms. Demographic characteristics (age, gender identity, and ethnicity) were incorporated as control variables.

Results

Sample

In total, 1640 individuals began the survey, 208 of whom did not complete it (a completion rate of 87.3%), resulting in a final sample of 1432 participants. The sample had a mean age of 34.1 years (range 18-83 years) and comprised predominately female participants (88.0%). Overall, the sample engaged in high levels of structured physical activity (M = 266.8 min per week, SD = 219.8), and 53.1% (n = 761) reported currently engaging with a physical activity app. Table 1 presents the demographic characteristics of app users and nonusers. There were no significant differences between the two groups (app users and nonusers) in relation to age, gender identity, or ethnicity. However, app users engaged in significantly more structured physical activity per week than nonusers (Table 1). Overall,

among those who reported engaging in physical activity, participants predominately engaged in individual physical activities (e.g., walking or running; 60.0%), followed by gym-based activities (e.g., gym classes; 41.0%), and sports-based activities (e.g., netball or football; 24.0%). This did not differ based on whether participants used an app. Relatedly, participants spent the most time engaging in individual activities per week (M = 141.7 min, SD = 185.2), followed by gym-based activities (M = 76.5 min, SD = 121.9), and sports-based activities (M = 48.1 min, SD = 116.2). App users spent significantly more time engaging in individual activities and gym-based activities than non-users (Table 1).

Table 1

Sample characteristics of physical activity app users and non-users

Characteristic	App users (n = 761)	Non-app users (n = 671)	P value	Effect Size
Age (years), *n* (%)				
18-25	243 (32.0)	257 (38.3)	.42	Φ = .12
>25-30	115 (15.0)	76 (11.4)		
>30-40	190 (25.0)	119 (17.7)		
>40	208 (27.3)	214 (31.9)		
Gender identity, *n* (%)				
Female	668 (88.8)	588 (88.0)	.94	Φ = .006
Male	84 (11.0)	73 (11.0)		
Ethnicity, *n* (%)				
Caucasian	682 (89.6)	581 (86.6)	.67	Φ = .05
Asian	35 (4.6)	37 (5.5)		
Indian	10 (1.3)	13 (1.9)		
Other	34 (4.5)	40 (6.0)		
Structured physical activity (mins per week), *M* (SD)	309.0 (214.0)	219.0 (216.0)	<.001	*d* = 0.42
Individual activities (*n* = 859)	170.0 (192.0)	110.0 (172.1)	<.001	*d* = 0.33
Sport based activities (*n* = 344)	50.8 (118.6)	45.0 (113.5)	.35	*d* = 0.05
Gym based activities (*n* = 588)	88.2 (122.0)	64.0 (120.6)	<.001	*d* = 0.20

Physical Activity App Use

Fitbit (22.5%), followed by Strava (17.1%) and Garmin (13.4%) were the most popular apps, and this did not differ by age or gender identity. Participants most commonly engaged with apps that had the capacity to exclusively track behaviours and predominately used apps for individual activities (e.g., running or walking). This was consistent across age and gender identities.

The greatest proportion of participants reported using their physical activity app on 7 occasions per week (39.0%), followed by use on 3 occasions (13.4%) and more than 7 occasions (9.2%) per week. A Kruskal-Wallis Test comparing weekly physical activity duration revealed a statistically significant difference ($P = .006$) across levels of app usage. Specifically, pairwise comparisons identified that participants who used the app on 6 occasions per week engaged in significantly higher levels of structured physical activity (*Mdn* = 491.9 min) than those who used the app on 2 occasions per week (*Mdn* = 297.4 min; $P = .003$). Overall, participants who used an app 6 times per week engaged in the highest levels of structured physical activity.

Use of Social Components of Physical Activity Apps

Among app users, 3.4% ($n = 26$) used app-specific communities exclusively, 59.9% ($n = 456$) used existing social networking platforms exclusively, and 22.0% ($n = 167$) used both app-specific communities and existing social networking platforms. This did not differ significantly by age, gender identity, ethnicity, capabilities of the app used (e.g., tracking), the type of physical activity the app was used for, or frequency of app usage per week.

App-Specific Communities

Among app users, 59.0% ($n = 447$) reported that the physical activity app they were currently using incorporated an app-specific community. Of these, 43.1% ($n = 193$) reported engaging with the community. Participants who reported engaging with the app-specific communities predominantly used Strava (41.5%, $n = 80$), Fitbit (20.7%, $n = 40$), and Garmin (6.7%, $n = 13$). Table 2 shows that the distribution of age was significantly different between app community users and nonusers. Specifically, app community users were predominately >30 years. App community users also engaged in significantly more structured physical activity per week than nonusers ($t(445) = 2.62$; $P = .009$; $d = 0.25$). However, there were no significant differences between users and nonusers of the app-specific community in relation

to gender identity, ethnicity, capabilities of the app used (e.g., tracking), the type of physical activity the app was used for, or app usage per week. Among participants who reported not engaging with the app-specific community (57.0%, *n* = 254), the reasons identified were privacy or security concerns, negative attitudes toward the use of the community, considered unnecessary, lack of support, beliefs regarding the nature of physical activity, disinterest in others' physical activity performance, and use of an alternative social network. Of these, the most commonly cited reasons were that the use of the community was considered unnecessary (33.4%, *n* = 83), disinterest in others' physical activity performance (20.3%, *n* = 50), and privacy or security concerns (17.5%, *n* = 43).

Among participants who engaged with the app-specific community (*n* = 193), users most frequently used features that allowed the sharing of physical activity performance, providing encouragement to others' physical activity posts (e.g., likes or positive comments), and receiving encouragement on one's own posts. These features were most frequently reported to be used with networks that were close friends or peers. There were no significant differences in engagement with features of app-specific communities across age, levels of app usage or according to capabilities of the app used, or the activity the app was used for.

Table 2

Sample characteristics of app-specific community users and non-users

Characteristic	Community users (*n* = 193)	Non-users (*n* = 254)	*P* value	Effect size
Age, *n* (%)				
18-25	34 (17.7)	77 (30.4)	.005	Φ = .16
>25-30	29 (15.1)	46 (18.2)		
>30-40	59 (30.6)	65 (25.7)		
>40	70 (36.2)	65 (25.7)		
Gender identity, *n* (%)				
Female	159 (82.4)	229 (90.2)	.05	Φ = .090
Male	29 (15.0)	24 (9.4)		
Ethnicity, *n* (%)				
Caucasian	177 (91.7)	231 (90.9)	.45	Φ = .112
Asian	9 (4.7)	9 (3.5)		
Indian	2 (1.0)	4 (1.6)		
Other	5 (2.6)	10 (4.0)		
Structured physical activity (mins per week), *M* (*SD*)	357.69 (217.7)	305.42 (196.3)	.009	*d* = 0.25
Type of app, *n* (%)				
Tracking	184 (95.3)	234 (92.1)	.26	Φ = .094
Guided workouts	5 (2.6)	14 (5.5)		
Tracking & workouts	3 (1.6)	2 (0.8)		
Other (booking classes, immersive games)	1 (0.5)	4 (1.6)		
Physical activity app is used for, *n* (%)				
All daily activity	18 (9.3)	39 (15.3)	.23	Φ = .112
Individual activities	154 (80.0)	184 (72.4)		
Group based activities	0 (0.0)	1 (0.4)		
Gym based activities	10 (5.2)	18 (7.1)		
Individual/group based/gym activities	6 (3.1)	6 (2.4)		

Existing Social Networking Platforms

Among app users, 82.0% (n = 624) reported using existing social networking platforms (Facebook, Instagram, or Twitter) in relation to physical activity. There were no significant differences between users and nonusers of existing social networking platforms in relation to age, gender identity, or ethnicity. Participants who used existing social networking platforms engaged in significantly more structured physical activity than those who did not ($t(672) = 2.9$; $P = .004$; $d = 0.44$). The features of existing social networking platforms that were most frequently used were providing encouragement on others' physical activity posts, followed by receiving encouragement on one's own physical activity posts (e.g., likes or comments). Notably, there were significant differences in the frequency of engagement with features of existing social networking platforms based on age, both in terms of sharing physical activity posts ($F(3, 666) = 5.37$; $P = .001$) and engaging in comparisons ($F(3, 666) = 19.0$, $P < .001$). Specifically, participants aged 18-25 years shared posts to existing social networking platforms significantly less frequently than all other age groups. In addition, participants aged >40 years made significantly fewer comparisons relative to all other age groups. However, there were no significant differences in the frequency of engagement with features of existing social networking platforms across the frequency of app usage or according to the capabilities of the app used, or the activity the app was used for.

Exploring Predictors of Physical Activity

The regression model accounted for 42.6% of the variance in structured physical activity ($R^2 = 0.426$) and was significant ($F(38, 96) = 1.87$; $P < .01$). The following variables were significant positive predictors of structured physical activity: frequency of app use ($\beta = .25$; $P = .009$), providing encouragement to a partner ($\beta = .52$; $P = .005$), receiving encouragement from close friends ($\beta = .59$; $P = .01$) and family ($\beta = .48$; $P = .02$), engaging in competitions with members of a public app-specific community ($\beta = .38$; $P = .001$), and

sharing posts to existing social networking platforms (β = .31; *P* = .004). In addition, the following variables were significant negative predictors of structured physical activity: sharing physical activity posts with a partner (β = -.40; *P* = .007), providing encouragement to close friends (β = -.57; *P* = .01), receiving encouragement from members of a public app-specific community (β = -.35; *P* = .04), and engaging in competitions with a partner (β = -.30; *P* = .04 (see Table 3).

Table 3

Multiple regression analysis examining predictors of structured physical activity among app users

Variable	β	*t*	*P* Value
Gender	-.05	-.62	.53
Age	-.02	-.24	.81
Ethnicity	-.05	-.48	.63
App engagement (frequency)	.25	2.64	.009
Sharing posts			
Partner	-.40	-2.74	.007
Family	-.18	-1.09	.28
Close friends	.08	.50	.62
Peers	.02	.14	.88
Public app community	-.02	-.16	.87
Colleagues	-.15	-1.24	.21
Providing encouragement			
Partner	.52	2.90	.005
Family	-.08	-.45	.64
Close friends	-.57	-2.50	.01
Peers	.19	.96	.34
Public app community	.29	1.97	.05
Colleagues	.10	.53	.59
Receiving encouragement			
Partner	-.14	-.84	.40

Family	.48	2.28	.02
Close friends	.59	2.41	.01
Peers	.01	.07	.94
Public app community	-.35	-1.98	.04
Colleagues	-.15	-.81	.41
Engagement in competitions			
Partner	-.30	-2.0	.04
Family	-.06	-.40	.69
Close friends	-.16	-1.16	.24
Peers	-.18	-1.25	.21
Public app community	.38	3.27	.001
Colleagues	-.07	-.55	.57
Engagement in comparisons			
Partner	.15	.93	.35
Family	-.04	-.24	.81
Close friends	-.17	-1.05	.29
Peers	.15	.93	.35
Public app community	.01	.06	.94
Colleagues	.06	.35	.72
Existing social networking platforms			
Sharing posts	.31	2.92	.004
Providing encouragement	-.07	-.63	.52
Receiving encouragement	.16	1.43	.15
Engagement in comparisons	.02	.20	.83

Discussion

Principal Findings

This study aimed to provide a comprehensive examination of the use of commercial physical activity apps and the relationship between app usage and physical activity. In addition, we sought to explore the use of social components of apps (app-specific communities and existing social networking platforms) and their value in facilitating engagement in physical activity. This study is timely, given the ubiquity of commercial

physical activity apps coupled with the need to understand how specific components of these apps may be beneficial in facilitating physical activity.

Overall, the findings demonstrate that the use of physical activity apps is common, with over half of the participants reporting that they currently use a physical activity app. Our findings are consistent with Krebs and Duncan (2015), who reported that in a large, diverse US sample (50% female), 58.2% had downloaded a health-related app, of which 52.8% used the app to track physical activity. This reflects both the omnipresence of commercial physical activity apps and their capacity to have high-population level reach. Notably, physical activity app users engaged in significantly more structured physical activity, consistent with findings from a previous study documenting that physical activity app users were 27% more likely to engage in physical activity than nonusers (Litman et al., 2015). In this study, app users predominantly used Fitbit, Strava, and Garmin, with the primary function of these apps being to track or monitor behaviour. This may explain the higher levels of physical activity among app users, given that self-monitoring is a behaviour change technique consistently associated with increased physical activity (Greaves et al., 2011; Knittle et al., 2018). These findings suggest that commercial physical activity apps may have great potential to influence physical activity. However, it must be acknowledged that the causality of the relationship between app use and physical activity is presently unclear, in that those who engage in high levels of physical activity may be attracted to apps to monitor their behaviour. Longitudinal research with a cross-lagged design is needed to ascertain the direction of this relationship between app use and physical activity.

This study identified that participants most commonly engaged with physical activity apps on seven occasions per week, and in line with previous research (Schoeppe et al., 2016), the frequency of app usage was significantly associated with physical activity. Interestingly, participants who used the apps on six occasions per week engaged in the highest duration

(minutes) of structured physical activity per week. This indicates that relatively high app use is associated with high levels of physical activity, reflective of the previously cited dose-response relationship between app use and behavioural outcomes (e.g., physical activity) (Schoeppe et al., 2016). The present findings further highlight that app usage is an important consideration in appropriately leveraging apps to promote engagement in physical activity. This emphasises the importance of examining specific components of apps that may be harnessed to increase app usage, namely social components.

A novel aspect of this study was its comprehensive examination of the social components (app-specific communities and existing social networking platforms) of commercial physical activity apps. Interestingly, the use of the social components of apps differed markedly, such that most app users engaged exclusively with existing social networking platforms (in relation to physical activity; 59.9%), whereas far fewer engaged with both app-specific communities and existing social networking platforms (22.0%) or app-specific communities exclusively (3.4%). This is perhaps not surprising given that existing social networking platforms are immensely popular, afford widespread reach, and achieve high levels of sustained engagement (Statista, 2018). Age is another factor that may have contributed to the difference in the use of the social components of apps, such that users of app-specific communities were predominately >30 years (66.8%); by contrast, age was not associated with the use of existing social networking platforms. Commercial research indicates that existing social networking platforms (e.g., Facebook) are used among adults across all age groups, although the lowest use is among those aged ≥35 years (Statista, 2022). In line with our findings, it is possible that this demographic prefers to engage with communities (e.g., app communities such as running/ walking groups) composed of likeminded individuals who share a common behavioural goal. This suggests that app-specific communities are most appropriate for a specific subgroup of the population (>30

years), whereas existing social networking platforms could be harnessed for the population more broadly. Relatedly, future research could consider examining other factors that may influence the use of app-specific communities and/or existing social networking platforms, such as one's presence on social networking platforms (i.e., those with vs without an established social networking presence).

Despite the differences in the usage of app-specific communities and existing social networking platforms, the social features across both were used similarly, with providing and receiving encouragement the most popular features. Interestingly, the findings also indicate that demographic characteristics may be linked to the likelihood that individuals will utilise specific features. For example, in relation to existing social networking platforms, those aged 18-25 years shared posts less frequently than all other age groups. This conflicts with extant research pertaining to the use of existing social networking platforms (more broadly) indicating that sharing posts on these platforms is higher among younger age groups (Malik, Hiekkanen, & Nieminen, 2016). However, it is possible that this demographic chooses to share other types of content (e.g., travel, food, or fashion) rather than physical activity behaviour. Our findings further show that those aged >40 years engaged in comparisons less frequently relative to all other age groups, in line with evidence indicating a decrease in social comparison tendencies across the lifespan (Buunk, Dijkstra, & Bosma, 2020). When leveraging the features of social components of physical activity apps (e.g., existing social networking platforms), a one-size-fits-all approach is not appropriate, and individual differences must be considered. Future research may usefully extend this understanding by examining whether other individual difference factors such as psychological characteristics (competitiveness and social comparisons) may influence the use of specific features.

Notably, the use of app-specific communities and existing social networking platforms was associated with significantly higher engagement in structured physical activity.

This is a novel finding given that it suggests that the social components of apps may play a fundamental role in facilitating engagement in physical activity. This may be attributed to the unique capacity of app-specific communities and existing social networking platforms to generate social support (Santarossa, Kane, Senn, & Woodruff, 2018), an important determinant of engagement in physical activity (Trost, Owen, Bauman, Sallis, & Brown, 2002). Another explanation is that individuals who engage in more physical activity have more content to share and are more likely to engage with the social components of apps, which, in turn, may foster supportive interactions. This study demonstrates the value of social components of apps in facilitating physical activity and the need to further examine app-specific communities and existing social networking platforms in future research.

Finally, the regression analysis revealed that the frequency of app usage was a significant predictor of structured physical activity, indicating the need to determine strategies that will facilitate app use. Interestingly, in relation to app-specific communities, providing encouragement to a partner, receiving encouragement from close friends and family, and engagement in competitions with members of public app-specific communities were positive predictors of physical activity. Conversely, sharing physical activity posts and engaging in competitions with a partner, providing encouragement to close friends, and receiving encouragement from members of public app-specific communities were negative predictors of physical activity. These findings indicate that receiving encouragement from strong ties (close friends and family) is beneficial in facilitating engagement in physical activity, whereas receiving encouragement from weak ties (public app-specific communities) is not. This is consistent with previous research showing that strong ties provide emotional support (encouragement, empathy) (Granovetter, 1973; Williams, 2006), which is linked to improvements in health outcomes (Robinson et al., 2019), and an increased likelihood that one will initiate and maintain engagement in physical activity (Kouvonen et al., 2012).

Conversely, weak ties often only provide informational support (advice or suggestions) (Granovetter, 1973; Williams, 2006), shown to be negatively associated with health behaviour (Oeldorf-Hirsch, High, & Christensen, 2019), and this has been attributed to receiving information or advice that is unwanted or in surplus (McLaren & High, 2019). The findings do, however, suggest that engaging in competitions with weak ties (public app-specific communities) is advantageous in promoting physical activity, whereas engaging in competitions or behaviours that may generate competitions (sharing physical activity posts) with strong ties (e.g., partner) is negatively associated with physical activity. This is in line with existing research documenting that comparisons (generating competitions) with strong ties elicits greater pressure and fear of experiencing shame and embarrassment, ultimately decreasing the likelihood that one will engage in the behaviour (Garcia, Tor, & Schiff, 2013; Zhang & Centola, 2018). Together, these findings provide an important understanding of the specific features (and networks) of app-specific communities that are most beneficial in facilitating physical activity, and thus should be leveraged in future app-based interventions.

The regression analysis also showed that in relation to existing social networking platforms, sharing physical activity posts positively predicted engagement in physical activity. This is perhaps not surprising given that a recent study (Oeldorf-Hirsch et al., 2019) found that sharing posts related to tracked health information (e.g., physical activity, sleep, or calories) to existing social networking platforms is positively associated with social support, and this, in turn, predicts engagement in the associated health behaviour. This highlights the need for future research to further explore the use of existing social networking platforms in relation to physical activity apps and physical activity behaviour. In addition, future studies could explore how different social networking environments (e.g., network size or composition) may interact with apps to influence physical activity.

Implications

Our findings have important implications for informing the design of future app-based interventions. They demonstrate that commercial physical activity apps, in particular, those that facilitate self-monitoring (e.g., Fitbit, Strava, and Garmin) hold great potential to promote engagement in physical activity. The convenience, accessibility, and affordability of commercial apps coupled with their capacity to facilitate physical activity highlight that future app-based interventions should harness commercial apps, as opposed to previous interventions that have predominately incorporated researcher-developed apps (Petersen et al., 2019). The findings also indicate that the social components of apps are important in promoting physical activity, and thus, fundamental in the development of effective app-based interventions. More specifically, in relation to app-specific communities, receiving encouragement from close friends and family, providing encouragement to a partner, and engagement in competitions with members of public app-specific communities were shown to be the most beneficial features in facilitating physical activity, and thus, should be leveraged to maximise effectiveness. However, relatively few app users engaged with app-specific communities (43.1%), with commonly cited barriers to using the communities, including disinterest and privacy or security concerns. Nevertheless, app-specific communities show great potential in facilitating physical activity, and thus, these barriers must be considered and overcome in the design of future apps and app-based interventions. The findings also suggest that existing social networking platforms are commonly used in relation to physical activity, and notably, sharing physical activity posts to these platforms predicts engagement in physical activity. Thus, existing social networking platforms will be an important component of future app-based interventions given their capacity to achieve high levels of use and promote engagement in physical activity.

This study also has important implications for guiding future research. Experimental evidence is now needed to isolate the influence of the social components of apps and their associated features on physical activity. Future research should also endeavour to ascertain the mechanisms (e.g., social support and self-efficacy) underlying the capacity of app-specific communities and existing social networking platforms to facilitate physical activity. Finally, longitudinal research is needed to determine the value of app-specific communities and existing social networking platforms in promoting sustained app use, and thus prolonged engagement in physical activity.

Limitations

As with all studies, there are a number of limitations that need to be acknowledged. First, the sample consisted predominantly of white women (typical of health behaviour research; Ryan et al., 2019), and the participants' origin (country/region) was unknown. These two sample characteristics limit the generalisability of the findings to the population more broadly. Nevertheless, app usage rates were similar to those previously reported in a large, diverse US sample (Krebs & Duncan, 2015). Second, the sample as a whole engaged in high levels of structured physical activity, indicative of self-selection bias, and thus, may not be representative of the general population. Third, self-report measures were used to assess physical activity and commercial physical activity app use, which may be subject to reporting inaccuracies (under- or overreporting). In addition, the assessment of structured physical activity did not capture incidental physical activity, which is often recorded by apps that track or monitor daily or individual physical activities. Thus, future research should consider using accelerometer-derived measures of physical activity in conjunction with self-report measures that have the capacity to capture both structured and incidental physical activity. Similarly, the utilisation of objective measures of physical activity app use (e.g., Google Analytics) should also be considered. Finally, there are a number of factors that may influence app use

and/or the association between app use and physical activity such as socioeconomic status (SES), fitness device ownership, and overall engagement with the app-specific community, which were not measured in this study. Many physical activity apps are often used in conjunction with fitness devices (e.g., Fitbits and Apple Watches), which may be too expensive for some individuals. As such, future research could examine potential interactions between SES, fitness device ownership, app use, and physical activity.

Conclusions

Notwithstanding these limitations, this study provides an important contribution to existing literature by comprehensively exploring the use of commercial physical activity apps and their associated social components in a large cross-sectional sample. The findings indicated that the use of commercial physical activity apps facilitates engagement in physical activity, and therefore, have great potential to disseminate scalable interventions to improve health behaviour. This study also provided a nuanced insight into app-specific communities and existing social networking platforms, identifying that they are components of apps that are valuable in promoting physical activity, and should be harnessed in the development of future app-based interventions. Together, these findings highlight the importance of further examining the social components of apps and gaining an understanding of the mechanisms underlying their influence on physical activity. In so doing, this study has demonstrated that commercial physical activity apps afford high population level reach and hold great potential to facilitate engagement in physical activity. Thus, future interventions aimed at increasing physical activity should further explore commercial physical activity apps and their associated social components.

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CHAPTER 4: STUDY 3

Psychological mechanisms underlying the relationship between commercial physical activity app use and physical activity engagement

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Abstract

Purpose: Previous studies have indicated a relationship between the use of commercial physical activity apps (e.g., Fitbit, Strava) and physical activity engagement. The use of social components of such apps, in particular app-specific communities (connecting with other app users) and existing social networking platforms (e.g., Facebook) have the potential to enhance physical activity. This study aimed to explore the psychological mechanisms underlying the relationship between the use of commercial physical activity apps (and their social components) and physical activity engagement. **Method:** An online cross-sectional survey assessed physical activity, use of commercial physical activity apps (and their associated social components), and psychological constructs (social support, self-efficacy, motivation, trait competitiveness, trait social comparison). **Results:** 1274 adults aged 18–83 years (M_{age} = 34.1 ± 13.5 years, 87.6% female) participated. App use was positively associated with physical activity engagement. The relationship between app use and physical activity was fully mediated by social support, self-efficacy, intrinsic motivation and identified regulation. Trait competitiveness, but not trait social comparison, moderated the relationship between app use and physical activity. Most features (e.g., sharing posts, providing or receiving encouragement) of the social components of apps were positively associated with psychological constructs linked to engagement in physical activity. Mediation pathways linking features of existing social networking platforms with physical activity were found. Specifically, sharing posts was linked to higher engagement in physical activity via positive associations with self-efficacy, and receiving encouragement was linked to higher engagement in physical activity via positive associations with both self-efficacy and identified regulation. In addition, engagement in comparisons was associated with lower self-efficacy and higher external regulation, and in turn, lower physical activity. **Conclusions:** The relationship between the use of commercial physical activity apps and physical activity is

underpinned by social support, self-efficacy and autonomous types of motivation. The findings highlight the importance of trait competitiveness, which should be taken into consideration when leveraging physical activity apps. Overall, the present study demonstrated that commercial physical activity apps (and their social components) hold great potential to increase physical activity engagement given their associations with psychological constructs strongly linked with physical activity.

Introduction

Physical activity is associated with many health benefits, including a reduced risk of premature all-cause mortality, cardiovascular disease, stroke, hypertension, colon and breast cancer, diabetes mellitus, osteoporosis, and mental illness (Rhodes, Janssen, Bredin, Warburton, & Bauman, 2017). Thus, it is concerning that 28% of adults globally, and 37% of adults in high income Western countries are not meeting physical activity guidelines (150 min of at least moderate intensity physical activity per week (World Health Organisation, 2018). Effective interventions are therefore needed to promote physical activity. Physical activity apps are a medium that afford widespread reach, convenience and accessibility, and have the potential to disseminate scalable interventions to facilitate engagement in physical activity.

Existing literature indicates that the use of physical activity apps is associated with greater engagement in physical activity (Litman et al., 2015; Wang et al., 2019). However, it is currently unclear exactly how such apps function to facilitate this engagement in physical activity. Previous research has identified that interventions that effectively increase physical activity target theoretical constructs underpinned by behaviour change theory (McEwan et al., 2019; Michie et al., 2013; Webb, Joseph, Yardley, & Michie, 2010). In particular, constructs such as social support and self-efficacy are included in a myriad of behaviour change theories (Glanz & Bishop, 2010). Importantly, self-efficacy has been shown to be the strongest predictor of physical activity (Choi, Lee, Lee, Kang, & Choi, 2017), and a determinant of both one's initial motivation and prolonged engagement in physical activity (McAuley, 1992; Wallace, Buckworth, Kirby, & Sherman, 2000). In addition, social support has been consistently and strongly associated with physical activity (Anderson-Bill, Winett, & Wojcik, 2011; Trost, Owen, Bauman, Sallis, & Brown, 2002). It has also been linked to greater engagement with health interventions, a precursor to intervention effectiveness (Poirier &

Cobb, 2012). Given this, it is not surprising that evidence (Litman et al., 2015; Wang et al., 2019) suggests that self-efficacy and social support play an important role in the relationship between physical activity app use and physical activity. However, motivation is another construct that is a strong predictor of physical activity (Teixeira, Carraça, Markland, Silva, & Ryan, 2012), and thus should be considered in order to gain a comprehensive understanding of the mechanisms by which apps may promote engagement in physical activity.

Previous literature has suggested that motivation may underlie an app's capacity to facilitate engagement in physical activity (Hosseinpour & Terlutter, 2019). However, research is yet to explicitly examine the role of motivation in the relationship between app use and physical activity. A widely used theory of motivation is Self-determination Theory (Deci & Ryan, 1985), which distinguishes autonomous/ intrinsic (e.g., enjoyment, improved health) and controlling/extrinsic (e.g., modify weight or shape, seeking approval from others) forms of motivation. Notably, autonomous forms of motivation are documented to be the strongest predictor of long-term engagement in physical activity (Teixeira et al., 2012), an important consideration given that prolonged engagement in physical activity is imperative to attaining its associated health benefits (Warburton, Nicol, & Bredin, 2006). This highlights the need to examine motivation, specifically in the context of Self-determination Theory, to ascertain its role in the relationship between app use and physical activity engagement.

The role of individual difference characteristics should also be considered in the examination of the relationship between app use and physical activity. One such individual difference is trait social comparison, conceptualised as a relatively enduring trait level characteristic, whereby some individuals have a greater inherent drive to evaluate themselves in relation to others (Gibbons & Buunk, 1999). Higher trait level social comparison has been identified to predict concurrent engagement in physical activity (Luszczynska, Gibbons, Piko, & Tekozel, 2004), and moderate the effects of a group-based behavioural weight loss

intervention on long-term engagement in physical activity (Arigo & Butryn, 2019). This suggests that trait level social comparison may play an important role in the association between physical activity app use and physical activity engagement. Furthermore, social comparisons are suggested to be interconnected with competitiveness, such that comparisons facilitate the generation of competitive behaviour (Festinger, 1954). Extant literature has shown that competition facilitates significantly greater engagement in physical activity (Johannesson, Östling, & Ranehill, 2010; Prestwich et al., 2017). Trait individual differences also exist in competitiveness, such that some individuals exhibit a preference towards competition (Murayama & Elliot, 2012). Previous research in relation to trait competitiveness has primarily focused on its role in physical activity performance (intensity), and has shown that higher trait competitiveness increases physical activity intensity in competitive situations (Snyder, Anderson-Hanley, & Arciero, 2012). However, the relationship between trait competitiveness and physical activity, specifically in relation to physical activity apps (many of which incorporate social features that facilitate competition) remains unknown.

Social features are an increasingly common component of physical activity apps (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018; Conroy, Yang, & Maher, 2014; Mollee, Middelweerd, Kurvers, & Klein, 2017). Many apps incorporate app-specific communities (allowing users to interact with other app users) or have the capacity to facilitate connections to existing social networking platforms (e.g., Facebook, Instagram) (Mollee et al., 2017). This is important given that recent research indicates that the social components of apps (app-specific communities and existing social networking platforms) facilitate engagement in physical activity (Petersen, Kemps, Lewis, & Prichard, 2020). Moreover, a recent review (Petersen, Prichard, & Kemps, 2019) identified that existing social networking platforms are beneficial in enhancing engagement with physical activity apps, and by extension, in facilitating physical activity. However, as yet, previous research has not

ascertained how specific components of apps (e.g., social components) may promote engagement in physical activity. This highlights the need to examine the relationships between social components of apps and psychological constructs associated with physical activity (social support, self-efficacy, motivation), fundamental to effectively harnessing apps to facilitate engagement in physical activity.

To gain an insight into the previously established relationship between physical activity app use and physical activity, the present study aimed to examine the psychological mechanisms underlying the relationship between use (versus non-use) of commercial physical activity apps (and their associated social components) and physical activity engagement. It was predicted that this relationship would be mediated by social support, self-efficacy and motivation. It was further predicted that trait social comparison and trait competitiveness would act as moderators, such that the relationship between physical activity app use and physical activity engagement would be greater among those with higher levels of trait social comparison and competitiveness.

Method

Design

The study used a cross-sectional design. Ethical approval was obtained from the University's Social and Behavioural Research Ethics Committee (protocol no. 8232). All participants provided informed consent electronically.

Participants

Participants were adults, 18 years or older, and proficient in English. The sample comprised of 1274 participants recruited using social networking platforms (e.g., Facebook, Instagram, and Twitter) and the University Discipline of Psychology's online research participation system. The participants were a subset of a larger sample (n = 1432; Petersen et al., 2020) who had provided data to address the aims of the present study.

The authenticity of all participants was verified by checking that their IP addresses were not on a blacklist (detects Bots/Crawlers). A number of additional checks were conducted to further ensure the authenticity of participants' responses by examining: (1) data for unusual patterns (e.g., high numbers of certain response choices), (2) answers to open-ended questions (duplicate phrases, off topic or incoherent responses), (3) the time taken to complete the survey (extremely quickly or slowly), and (4) the time at which the survey was completed (e.g., duplicate time signatures). These steps were undertaken in consultation with a cyber-security specialist.

Procedure

Data were collected from February to April 2019 using an online survey conducted through the Qualtrics platform. The survey incorporated the measures listed below in order of presentation (Appendix C) and took approximately 30 min to complete. Participants were provided with the opportunity to enter a raffle to win one of five AUD25 shopping gift vouchers in recognition of their time commitment.

Measures

Demographics. All participants were invited to report their age, gender and ethnicity.

Regular physical activity. Participants were asked to self-report their regular physical activity levels by specifying the type, duration and frequency of structured physical activity/sport they engage in on a weekly basis. Following Prichard and Tiggemann (2008), weekly physical activity minutes were calculated by multiplying the frequency of each activity by its duration.

Current physical activity app use. Participants were asked to self-report if they were currently using a physical activity app, defined as an app that has the capacity to track/ monitor physical activity (e.g., steps, distance) or provide guided training/workouts. Participants who reported using a physical activity app were invited to specify the name of

the app they were currently using most frequently (main physical activity app) (e.g., Strava), and their level of engagement with the app (number of times used per week).

Engagement with app-specific communities. Engagement with the app-specific community of the main physical activity app was assessed by items consistent with Petersen et al. (2020). Participants were asked to indicate how often on a 6-point Likert scale ranging from 0 (*never*) to 5 (*very often*) they engaged with specific members of the app community (e.g., partner, family, close friends) in relation to the following features: sharing physical activity posts, liking and/or providing positive comments on others' posts, receiving likes and/or positive comments, comparing their physical activity performance to others, and engaging in competitions. Following Petersen et al. (2020), as the networks within each feature were highly correlated ($\alpha = .74$), a composite score was calculated for the use of each specific feature of the app community (e.g., sharing) across the different networks (e.g., partner, family).

Engagement with existing social networking platforms. Physical activity related use of existing social networking platforms was measured as per Petersen et al. (2020). Participants were asked to indicate on a 6-point Likert scale how often (from *never* (0) to *very often* (5)) they share physical activity posts, like and/or provide positive comments on others' posts, receive likes and/or positive comments, and compare their physical activity performance to others' physical activity posts on Facebook, Instagram, or Twitter (plus the option to specify other platform(s)). As the platforms within each feature were correlated ($\alpha = .60$), a composite score was calculated for the use of each specific feature (e.g., sharing) across the different social networking platforms (e.g., Facebook, Instagram). This resulted in one score (ranging from 0 to 5) for each feature.

Perceived social support. Perceived social support for physical activity was measured using the Social Support for Exercise Behaviors Scale (Sallis, Grossman, Pinski,

Patterson, & Nader, 1987). The measure consists of 26 items; 13 items assess support provided by family, and 13 assess support provided by friends. The items are rated on a 5-point Likert scale from 1 *(never*) to 5 (*very often*). The 26 items were averaged to generate a composite score (Sallis et al., 1987), whereby a higher score indicated greater perceived social support from family and friends. In the present study, the internal reliability was high (α = .92).

Physical activity self-efficacy. The Physical Activity Self-efficacy Scale (Schwarzer & Renner, 2009) was used to assess perceived self-efficacy for physical activity, specifically determining one's capacity to engage in physical activity in the presence of various barriers (e.g., tired, depressed). The scale consists of 5 items that are rated on a 4-point Likert scale from 1 (*very uncertain*) to 4 (*very certain*). The 5 items are averaged to generate a composite score, with a higher score indicating higher perceived self-efficacy for physical activity. The internal reliability in the present sample was high (α = .91).

Behavioural regulation motives. The Behavioral Regulation in Exercise Questionnaire (BREQ-2) (Markland & Tobin, 2004) was used to assess motivation for physical activity based on Self-determination Theory. The questionnaire consists of 19 items, comprising 5 subscales assessing intrinsic motivation (4 items), identified regulation (4 items), introjected regulation (3 items), external regulation (4 items) and amotivation (4 items). Items are rated on a 5-point Likert Scale from 0 (*not true for me*) to 4 (*very true for me*). The reliability for each subscale was high; intrinsic motivation (α = .94), identified regulation (α = .84), introjected regulation (α = .84), external regulation (α = .83) and amotivation (α = .88).

Trait social comparison. Individual differences in social comparison were assessed using the Iowa-Netherlands Comparison Orientation Measure (Gibbons & Buunk, 1999). The measure incorporates 11 statements that are rated on a 5- point Likert scale from 1 (*strongly*

disagree) to 5 (*strongly agree*). The items were averaged, and higher scores indicate higher comparison tendencies. In the current study, the Cronbach alpha was .85.

Trait competitiveness. The Revised Competitiveness Index (Houston, Harris, McIntire, & Francis, 2002) was used to assess competitiveness. The measure consists of 14 items reported on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). The Index is composed of two subscales assessing enjoyment of competition and contentiousness. In line with the objectives of the present study, the 9-item enjoyment of competition subscale was used. The scores were averaged, where higher scores were reflective of greater trait competitiveness. The internal reliability of the competition subscale in this sample was high ($\alpha = .94$).

Statistical Analysis

Statistical analyses were conducted using IBM Statistical Package for the Social Sciences (SPSS) version 25 and Mplus version 8. Alpha was set at 0.05. Descriptive statistics were used to summarise demographic information. A series of independent samples *t*-tests and one-way between-groups multivariate analysis of variance (MANOVA) were used to determine differences between app users and non-users in relation to psychological constructs (e.g., social support, self-efficacy and motivations).

Structural equation modelling (SEM) was conducted in Mplus using maximum likelihood estimation to examine whether social support, self-efficacy and motivations mediated the relationship between app use and physical activity. Following Preacher and Hayes (2008) procedure, mediation effects were tested by calculating 95% confidence intervals using a bootstrapped resampling method (5000 samples). Mediation is established when the indirect effect is deemed significant, such that the 95% confidence interval does not contain zero. As our aim was to estimate specific (i.e., direct and mediation) effects of app use on physical activity rather than the fit of the whole model, no goodness-of-fit statistics are

reported. Missing data (< 5%) were handled with Full Information Maximum Likelihood (FIML), a robust strategy which estimates model parameters using all available data (Allison, 2003; Enders & Bandalos, 2001).

Mplus was also used to examine whether trait social comparison and competitiveness independently moderated the effect of app use on physical activity. Two separate structural moderated models (one for each proposed moderator variable) were conducted. The moderator variables (trait social comparison and competitiveness) were grand-mean centred.

In relation to examining the social components of physical activity apps, Pearson bivariate correlations were used to assess the associations between engagement with features of app-specific communities and existing social networking platforms and psychological constructs. We further conducted two larger structural equation models to simultaneously examine the effects of all features of either app-specific communities (Appendix D) or existing social networking platforms (Appendix E) on physical activity via psychological constructs. Again, as we sought to estimate specific (i.e., direct and mediation) effects of features of app-specific communities and existing social networking platforms on physical activity rather than on the fit of the model as a whole, no goodness-of-fit statistics are reported. Missing data (< 5%) were again handled with FIML.

Results

Sample

The initial sample consisted of 1432 participants. After excluding participants who did not provide any data on physical activity engagement, physical activity app use or psychological characteristics, our final sample comprised of 1274 participants. Demographic characteristics are presented in Table 1. Participants were predominately female (87.6%), ranging in age from 18 to 83 years (M = 34.1 years, SD = 13.5). On average, the sample engaged in 271.6 min (SD = 219.6) of physical activity per week. There were no significant

differences in physical activity engagement between age groups, ($F(3, 1263) = 0.88$, $P = .448$).

Table 1

Demographic characteristics (n = 1274)

Characteristic	
Age (years), *n* (%)	
18-24	417 (32.7)
25-44	552 (43.3)
45-64	270 (21.2)
>65	28 (2.2)
Gender, *n* (%)	
Female	1117 (87.6)
Male	143 (11.2)
Ethnicity, *n* (%)	
Caucasian	1129 (88.6)
Asian	65 (5.2)
Indian	18 (1.4)
Other	62 (4.8)
Physical activity (min/week), *M* (*SD*)	271.6 (219.6)
18-24	260.6 (227.6)
25-44	271.8 (208.4)
45-64	286.1 (224.5)
>65	299.2 (268.1)
Current use of a physical activity app, *n* (%)	
18-24	189 (45.3)
25-44	328 (59.4)
45-64	126 (46.7)
>65	9 (32.1)
Social support, *M (SD)*	1.9 (0.7)
Self-efficacy, *M (SD)*	2.6 (0.8)
Motivations, *M (SD)*	
Intrinsic	3.7 (1.1)
Identified	3.9 (0.9)

Introjected	2.9 (1.2)
External	1.6 (0.9)
Amotivation	1.4 (0.7)
Trait level constructs, *M (SD)*	
Competitiveness	3.2 (0.9)
Social comparison	3.3 (0.7)

Over half of participants (51.4%, $n = 655$) reported currently using a physical activity app. App use did not differ by gender or ethnicity, but it did significantly differ by age group, such that a significantly greater proportion of participants aged 25–44 years were currently using a physical activity app than all other age groups, $\chi^2(1) = 26.9$, $P < .001$, $\phi = 0.146$. The apps most commonly used were Fitbit (22%), Strava (16%) and Garmin (14%). Physical activity app users predominately reported daily use of the apps (37.3%), followed by use on 3 occasions per week (13.3%). Overall, app users ($M = 316.3$, $SD = 213.5$) engaged in significantly more physical activity per week than non-users ($M = 224.3$, $SD = 216.2$), $t(1272) = 7.6$, $P < .001$, $d = 0.43$.

Among app users, 64% ($n = 417$) reported that the main physical activity app they were currently using incorporated an app-specific community, of which 41% ($n = 171$) reported engaging with it. In addition, 92.5% ($n = 606$) of app users reported engaging with existing social networking platforms in relation to physical activity. Participants who engaged with app-specific communities ($t(415) = 2.93$, $P = .003$, $d = 0.30$) or existing social networking platforms ($t(653) = 2.90$, $P = .004$, $d = 0.40$) engaged in significantly higher levels of physical activity than participants who did not engage with these features.

App Use and Physical Activity

Table 2 presents the differences among current physical activity app users and non-users in relation to psychological constructs associated with physical activity behaviour. App users reported significantly higher social support, and self-efficacy than non-users. In relation

to motivations, app users reported significantly higher intrinsic motivation, identified and introjected regulation, and significantly lower amotivation than non-users. App users also demonstrated significantly higher trait competitiveness than non-users; however, there were no differences between the two groups in trait social comparison.

Table 2

Psychological characteristics of users and non-users of physical activity apps

Characteristic, *M (SD)*	App users (n = 655)	Non-app users (n = 619)	*P* value	Effect size
Social support	2.0 (0.7)	1.7 (0.6)	<.001	d = 0.50
Self-efficacy	2.8 (0.7)	2.4 (0.8)	<.001	d = 0.53
Motivations				
Intrinsic	3.9 (1.0)	3.4 (1.2)	<.001	η^2 = .062
Identified	4.2 (0.8)	3.7 (1.0)	<.001	η^2 = .080
Introjected	3.0 (1.2)	2.7 (1.2)	<.001	η^2 = .016
External	1.6 (0.8)	1.7 (0.9)	.077	η^2 = .003
Amotivation	1.3 (0.6)	1.5 (0.8)	<.001	η^2 = .020
Trait level constructs				
Competitiveness	3.3 (0.9)	2.9 (0.9)	<.001	d = 0.44
Social comparison	3.3 (0.7)	3.2 (0.7)	.335	d = 0.14

The Roles of Social Support, Self-Efficacy, and Motivation in the Relationship between App Use and Physical Activity

Figure 1 depicts the SEM examining the relationships between app use, physical activity and psychological constructs associated with physical activity (social support, self-efficacy and motivations). Overall, the model accounted for a significant (P < .001) amount of variance in physical activity (22.2%). There were significant indirect effects of app use on physical activity via social support (β = 0.02 [0.009, 0.04]), self-efficacy (β = 0.06 [0.04, 0.08]), intrinsic motivation (β = 0.02 [0.004, 0.04]), and identified regulation (β = 0.08 [0.06,

0.11]). Thus, the findings indicate that the relationship between app use and physical activity was mediated by social support, self-efficacy, intrinsic motivation and identified regulation. The direct effect of app use on physical activity was no longer significant, indicating complete mediation.

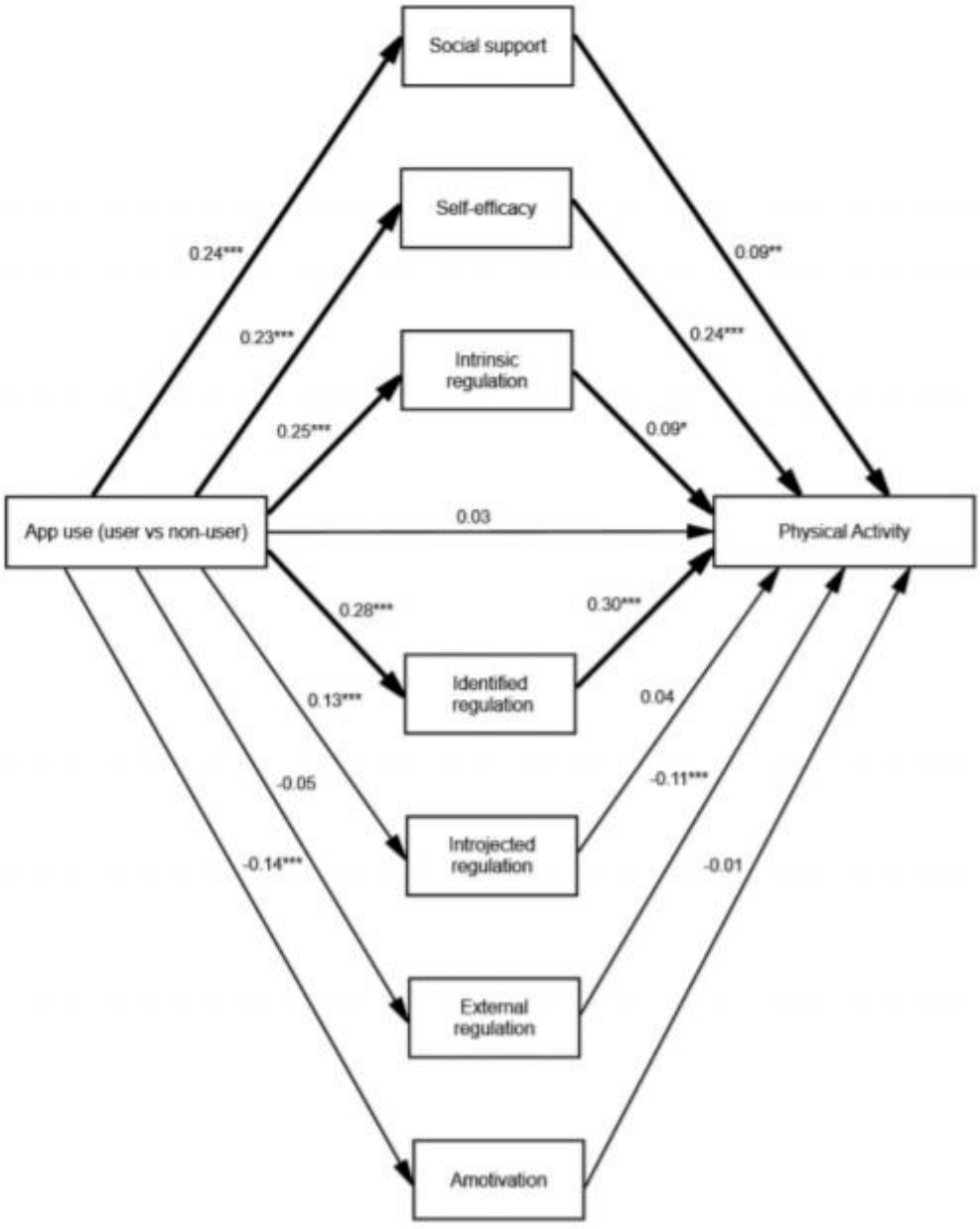

Figure 1. Mediation pathway: roles of social support, self-efficacy, and motivation in the relationship between app use and physical activity.

Note. Significant indirect paths are shown in bold. *$P < .05$, **$P < .01$, ***$P < .001$.

Moderating Role of Trait Level Constructs in the Relationship between App Use and Physical Activity

The moderation analyses identified that trait social comparison was not a significant predictor of physical activity (β = 0.02, *P* > .05), nor was the interaction term (product of app use and trait social comparison) (β = -0.03, *P* > .05). However, trait competitiveness (β = 0.10, *P* < .01) and the interaction term (product of app use and trait competitiveness) (β = 0.21, *P* < .05) were significant predictors of physical activity. This indicates that the relationship between app use and engagement in physical activity varied according to trait level competitiveness. Simple slopes were estimated at one SD above (high) and below (low) the sample mean for trait competitiveness to explore the interaction. As shown in Figure 2, app use was more strongly predictive of engagement in physical activity in those with higher trait competitiveness (*B* = 103.4, *P* < .001) than those with lower trait competitiveness (*B* = 54.5, *P* < .01).

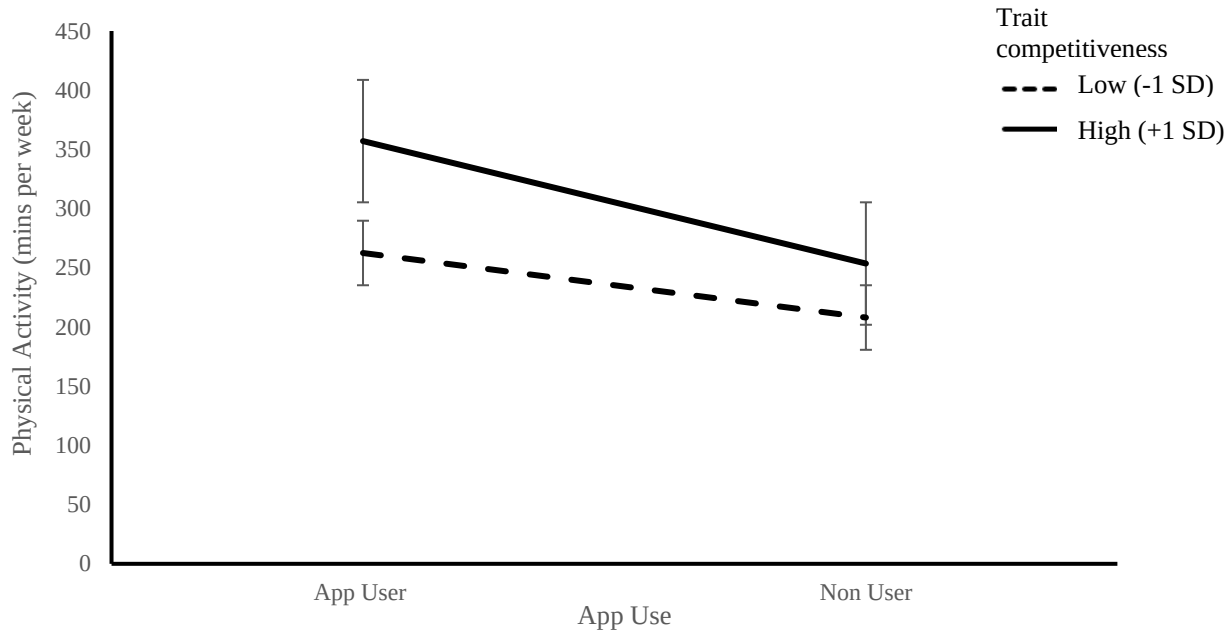

Figure 2. Interaction between app use and trait competitiveness in predicting physical activity engagement.

Social Components of Apps and Physical Activity

Among participants who used apps (n = 655), the associations between engagement with the features of app-specific communities and existing social networking platforms and psychological constructs associated with physical activity are presented in Table 3. Social support was positively associated with the use of all features of app-specific communities and existing social networking platforms. There were also positive associations between self-efficacy and engagement with several features of app-specific communities and existing social networking platforms (e.g., sharing posts, providing/receiving encouragement, and engagement in comparisons). The features of app-specific communities and existing social networking platforms were predominately positively associated with intrinsic motivation and identified regulation. In addition, most features of existing social networking platforms were positively associated with introjected regulation.

Table 3

Correlation coefficients for features of app-specific communities and existing social networking platforms and psychological constructs

	Social support	Self-efficacy	Intrinsic motivation	Identified regulation	Introjected regulation	External regulation	Amotivation
App-specific communities (*n* = 171)							
Sharing posts	.392**	.089	.200*	.099	.055	.050	-.023
Providing encouragement	.380**	.252**	.326**	.211**	-.017	-.136	-.076
Receiving encouragement	.429**	.243**	.307**	.174*	.005	-.046	-.010
Engagement in comparisons	.396**	.156*	.141	.104	.031	.136	.038
Engagement in competitions	.357**	.110	.097	.071	.031	.067	.080
Existing social networking platforms (*n* = 606)							
Sharing posts	.211**	.223**	.232**	.274**	.161**	-.070	-.107**
Providing encouragement	.239**	.126**	.177**	.213**	.142**	-.041	-.024
Receiving encouragement	.277**	.173**	.160**	.198**	.077	.008	.032
Engagement in comparisons	195**	-.013	.078	.118**	.241**	.118**	.026

Note. *$P < .05$, **$P < .01$

Mediation Examining the Roles of Social Support, Self-Efficacy and Motivation in the Relationships between Social Components of Apps and Physical Activity

App-Specific Communities

The SEM incorporating all features of app-specific communities accounted for a significant ($P < .001$) amount of variance in physical activity (31.3%). There were significant direct paths from providing encouragement to external regulation (β = -0.68 [-1.0, -0.35]) and amotivation (β = -0.40 [-0.76, -0.05]), and from engagement in comparisons to external regulation (β = 0.31 [0.14, 0.51]). Additionally, paths to physical activity were significant for self-efficacy (β = 0.35 [0.18, 0.50]), identified regulation (β = 0.26 [0.06, 0.45]), and introjected regulation (β = 0.24 [0.07, 0.38]). However, this model did not show any indirect effects of features of app-specific communities on physical activity via the psychological constructs.

Existing Social Networking Platforms

The SEM incorporating all features of existing social networking platforms simultaneously accounted for a significant ($P < .001$) amount of variance in physical activity (24.8%). There were significant direct paths from sharing posts to self-efficacy (β = 0.13 [0.004, 0.22]), and from receiving encouragement to social support (β = 0.31 [0.21, 0.41]), self-efficacy (β = 0.42 [0.31, 0.52]), intrinsic regulation (β = 0.49 [0.36, 0.62]), identified regulation (β = 0.54 [0.39, 0.67]), external regulation (β = -0.23 [-0.39, -0.06]) and amotivation (β = -0.32) [-0.50, -0.11]). Additionally, there were significant direct paths from engagement in comparisons to self-efficacy (β = -0.16 [-0.26, -0.07]), introjected regulation (β = 0.21 [0.13, 0.30]), external regulation (β = 0.21 [0.12, 0.30]), and amotivation (β = 0.09 [0.006, 0.19]). Furthermore, paths to physical activity were significant for self-efficacy (β = 0.21 [0.13, 0.28]), identified regulation (β = 0.25 [0.14, 0.35]), and external regulation (β = -0.09 [-0.17, -0.02]). The indirect effects of sharing posts on physical activity was mediated by

self-efficacy (β = 0.03 [0.001, 0.05]. This indicates that sharing posts is associated with higher self-efficacy, and in turn, greater engagement in physical activity. The effect of receiving encouragement on physical activity was mediated by both self-efficacy (β = 0.09 [0.05, 0.13]) and identified regulation (0.13 [0.07, 0.21]. In particular, receiving encouragement was positively associated with self-efficacy and identified regulation, which were, in turn, associated with greater physical activity. Finally, the effect of engagement in comparisons on physical activity was mediated by self-efficacy (β = -0.03 [-0.06, -0.01]) and external regulation (β = -0.02 [-0.04, -0.004]). Specifically, higher engagement in comparisons was associated with lower self-efficacy and higher external regulation, which were, in turn, linked to decreased physical activity.

Discussion

This study aimed to gain insight into the psychological mechanisms underlying the previously established relationship between commercial app use and physical activity engagement. We focused specifically on social support, self-efficacy and motivation as potential mechanisms underlying the link between the use of commercial apps (and their associated social components) and physical activity. The role of individual difference characteristics (i.e., trait competitiveness and trait social comparison) was also explored.

The findings demonstrated that commercial physical activity app use was associated with greater engagement in physical activity, consistent with existing research (Litman et al., 2015; Wang et al., 2019). Physical activity app users also reported higher social support, self-efficacy and motivation (autonomous and controlled forms), all constructs which have been consistently associated with physical activity engagement (Choi et al., 2017; Teixeira et al., 2012; Trost et al., 2002). Further, the findings demonstrated that the relationship between commercial app use and physical activity was fully mediated by social support, self-efficacy and autonomous types of motivation (intrinsic motivation and identified regulation). This

finding is consistent with previous research suggesting that social support and self-efficacy underlie the association between app use and physical activity (Litman et al., 2015; Wang et al., 2019). However, as an important extension, the present study ascertained the role of motivation, a construct that is a strong predictor of physical activity (Teixeira et al., 2012), and underpinned by Self-determination Theory (Deci & Ryan, 1985). The findings showed that app users are motivated by both the enjoyment derived from physical activity (intrinsic motivation), and the personal value placed on the outcomes of physical activity (identified regulation), and these motivations in turn predicted greater engagement in physical activity. This finding is notable given the previously established association between autonomous types of motivation (intrinsic motivation and identified regulation) and prolonged engagement in physical activity (Teixeira et al., 2012), suggesting that physical activity apps may be important in facilitating sustained engagement in physical activity. Future research should explore the impact of commercial app use on long-term engagement in physical activity.

A further aim of the present study was to examine the roles of trait competitiveness and trait social comparison in the relationship between app use and physical activity. The findings identified that trait competitiveness moderated the relationship between app use and physical activity, but trait social comparison did not. More specifically, individuals with higher levels of trait competitiveness engaged in significantly higher levels of physical activity, suggesting that those with a general disposition toward competition may benefit most from using apps. This is not altogether surprising given that apps increasingly incorporate ‘gamification’, that is, features that facilitate competitions (e.g., leader boards, daily/weekly challenges, points, badges) (Edwards et al., 2016). Research on gamification suggests that not all individuals are similarly motivated by competitive features, and thus a one-size fits all approach is not appropriate (Hamari, Koivisto, & Sarsa, 2014). In particular,

certain personality traits (e.g., extraversion, emotional stability) are associated with preferences for specific gamification features (Jia, Xu, Karanam, & Voida, 2016), and individual (e.g., self-efficacy) as well as environmental factors (e.g., perceived competitive climate) can influence the effects of competitive elements (e.g., leader boards) on physical activity behaviour (Wu, Kankanhalli, & Huang, 2015). The present study adds to the existing literature by suggesting that in the context of physical activity apps, trait level differences, in particular trait competitiveness enhances the capacity of competitive features to facilitate physical activity.

The findings also demonstrated that trait social comparison did not moderate the relationship between app use and physical activity. One possible explanation is that social comparisons inherently require connecting with others (e.g., other app users); yet, less than half of the participants indicated engaging with other users within the app. By contrast, engagement in competitions may occur regardless of whether one connects with other app users, such that individuals may compete with their own previous personal performance (e.g., daily steps, activity minutes) or with other individuals. Another possibility is that our use of a general measure to assess trait social comparisons may not have adequately captured participants' tendencies to engage in physical activity comparisons, as the items broadly assessed engagement in comparisons (e.g., "I always pay a lot of attention to how I do things compared with how others do things"). Additionally, there is some evidence to suggest that the type of comparison (i.e., upward or downward) differentially impacts physical activity (Huang, Sun, & Jiang, 2022), and this too was not assessed in the present study. A context-specific state measure that assesses comparisons specifically in relation to physical activity (and their direction) should be considered in future research. It should be noted, however, that little research exists in relation to leveraging competitions and social comparisons to

maximise the effectiveness of commercial physical activity apps, and thus further exploration is warranted.

The present study identified that the use of the social components of commercial physical activity apps (app-specific communities and existing social networking platforms) was associated with significantly higher engagement in physical activity. This study is the first to examine the mechanisms that may underlie the capacity of these social components to facilitate physical activity. The findings identified that most features of app-specific communities and existing social networking platforms were positively associated with psychological constructs that have consistently been linked to engagement in physical activity. Notably, our findings further demonstrated that for existing social networking platforms, self-efficacy and identified regulation mediated the positive effect of receiving encouragement on physical activity. Additionally, self-efficacy also mediated the positive effect of sharing posts on physical activity. This suggests that specific features of existing social networking platforms may play a role in an individual's beliefs pertaining to their ability to perform physical activity (self-efficacy), and the personal value one places on the outcomes of physical activity (identified regulation), both of which, are consistently shown to be strong predictors of sustained engagement in physical activity (Sallis, Hovell, & Hofstetter, 1992; Teixeira et al., 2012). It is also important to note that research suggests that social support is a precursor to self-efficacy (Bandura, Freeman, & Lightsey, 1999). Thus, it is possible that in the present study, sharing posts and receiving encouragement may have facilitated the provision of social support, and in turn self-efficacy. This fits with existing cross-sectional research (Oeldorf-Hirsch, High, & Christensen, 2019) showing that sharing posts to existing social networking platforms about tracked health information (e.g., physical activity, sleep, calories) is positively associated with social support. Thus, it appears that features of existing social networking platforms may be particularly beneficial in facilitating

physical activity. In addition, physical activity related use of existing social networking platforms does not differ across age groups (Petersen et al., 2020), suggesting that these platforms could be harnessed to support physical activity for the population more broadly. Future experimental research should further explore existing social networking platforms, and their value in promoting engagement in physical activity.

Interestingly, our findings also showed that self-efficacy and external regulation mediated the relationship between engagement in comparisons (on existing social networking platforms) and physical activity. In particular, we found that engagement in comparisons was related to lower beliefs in one's ability to perform physical activity (self-efficacy) but higher motivation on the basis of obtaining rewards or avoiding punishments (external regulation), which translated into decreased physical activity behaviour. Previously, research has suggested that comparisons may be beneficial in facilitating physical activity (Luszczynska et al., 2004), while other evidence has indicated that comparisons may be demotivating for physical activity (Arigo, Pasko, & Mogle, 2020). This mixed evidence is suggested to be attributed to individual differences in factors such as social comparison orientation, comparison frequency and appearance satisfaction, which have been shown to influence whether a comparison is harmful or beneficial in supporting health behaviour (Arigo et al., 2020; Pila, Barlow, Wrosch, & Sabiston, 2016). The present study adds to the existing literature by identifying the mechanisms (low self-efficacy and high external regulation) underlying comparisons that are harmful to health behaviours (i.e., physical activity). Future research should ascertain how to most effectively harness comparisons to support health behaviour, which for existing social networking platforms may include identifying the type and content of posts that are most beneficial.

The present study has important implications for informing the development of future physical activity interventions. Our findings indicate that over half of the sample were

currently using a physical activity app, and app use was highest among individuals aged 25–44 years, in line with previous findings that app users tend to be younger (Bol, Helberger, & Weert, 2018; Krebs & Duncan, 2015). However, a large proportion of all our age groups were using apps. This is perhaps not surprising given the rapid increase in the adoption of health apps across all ages (Corbett, Huggins, Price, & Twibill, 2019), and accumulating evidence suggesting that apps are feasible for, and acceptable by older adults (>65 years) (Li et al., 2020; Lyons, Swartz, Lewis, Martinez, & Jennings, 2017). Relatedly, physical activity apps have been documented to incorporate a range of behaviour change techniques (e.g., feedback, self-monitoring, goal-setting, demonstration of behaviour, social support) (Bondaronek et al., 2018), many of which have been shown to facilitate physical activity engagement both in the general adult population (Greaves et al., 2011; Michie, Abraham, Whittington, McAteer, & Gupta, 2009) and older adults (Arnautovska, O'Callaghan, & Hamilton, 2018). Thus, commercial physical activity apps are clearly beneficial given their widespread reach, acceptability by the population at large, and based on the current findings, are associated with certain psychological constructs (i.e., social support, self-efficacy and motivation) which have been linked to increased physical activity behaviour. Accordingly, commercial physical activity apps should be leveraged to develop effective, scalable app-based interventions in the future. Collaborations between researchers and commercial app developers may be beneficial during both the development and evaluation of app-based interventions.

Leveraging social components will also be fundamental in the development of effective physical activity interventions. In particular, features of existing social networking platforms (sharing and receiving encouragement) show great promise given their association with self-efficacy, a strong predictor of physical activity engagement. This knowledge is important in informing the design of physical activity interventions that harness the social

components of commercial physical activity apps. Specifically, it appears that app-based interventions that promote sharing physical activity data to an existing social networking platform (generating positive encouragement) may be most beneficial in promoting physical activity engagement.

Our findings also have important implications for guiding future research. More specifically, well-designed randomised controlled trials are now needed to rigorously evaluate the effectiveness of interventions incorporating commercial physical activity apps and their associated social components. Vandelanotte et al. (2019) recommend that ecologically valid trials are also necessary to examine the engagement with, and effectiveness of, health apps in real-world circumstances. It should be acknowledged that while the present study indicates that psychological constructs (social support, self-efficacy and motivation) underlie the relationship between app use and physical activity engagement, the cross-sectional nature of this study precludes conclusions about causality. Thus, experimental and longitudinal research is needed to further examine the associations found in this study. Future research should also explore how competitions and comparisons may best be leveraged in relation to physical activity apps. Finally, the long-term impact of commercial app use on physical activity should be examined, to assess its capacity to facilitate sustained engagement.

As with all research, there are limitations that should be acknowledged. More specifically, the sample consisted predominantly of women, and the participants' origin (country/region) was unknown. This may limit the generalisability of the findings to the population more broadly. Additionally, physical activity engagement and commercial physical activity app use were measured via self-report, which may be subject to potential biases (e.g., social desirability) or reporting inaccuracies (e.g., over-reporting). Future

research would benefit from using accelerometer-derived measures of physical activity and objective assessments of app use (e.g., Google Analytics).

In conclusion, the present study provides a valuable contribution to the literature by demonstrating that social support, self-efficacy and autonomous types of motivation underpin the relationship between the use of commercial physical activity apps (and their associated social components) and physical activity engagement. Additionally, this is the first study to ascertain the role of individual differences in the relationship between app use and physical activity, with the findings suggesting that competitive individuals may benefit most from the use of commercial physical activity apps. Commercial physical activity apps hold great potential to increase physical activity, given their associations with psychological constructs that are strongly linked to physical activity engagement, and grounded in behaviour change theory. Experimental research is now needed to rigorously evaluate the capacity of commercial physical activity apps and their associated social components to improve physical activity behaviour.

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CHAPTER 5: STUDY 4

Tracking physical activity over time: associations between commercial physical activity app use, psychological constructs, and physical activity engagement

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Abstract

Purpose: Commercial physical activity apps (e.g., Fitbit, Strava) present unparalleled opportunities to promote physical activity engagement. There is a dearth of evidence about the long-term effectiveness of these apps. This study aimed to examine the associations between the use of commercial physical activity apps (and their social networking functionalities; app communities, existing social networking platforms) and engagement in physical activity over a 6-month period. The roles of social support, self-efficacy, and motivation were also investigated. **Method:** An online survey assessed physical activity, engagement with commercial physical activity apps (and their social networking functionalities), and social support, self-efficacy, and motivation, at three time points (baseline, 3 and 6 months). Data were analysed using Generalised Estimating Equations. Alpha was set at 0.05. **Results:** Participants were 731 adults aged 18 to 74 years (M_{age} = 34.1 ± 13.3 years, 88.0% female). Approximately half of the participants reported using a physical activity app at all time points. App users engaged in significantly higher levels of physical activity than non-users over the 6-month period (B = 59.3, $P < .001$). Among app users, sharing physical activity behaviour to existing social networking platforms predicted physical activity engagement (B = 41.0, $P = .040$). When adjusting for social support, self-efficacy and motivation, physical activity app use and sharing physical activity to existing social networking platforms were no longer significant predictors of physical activity engagement. Instead, identified regulation (B = 57.6, $P < .001$), self-efficacy (B = 55.0, $P < .001$), social support (B = 46.3, $P < .001$), and introjected regulation (B = 13.6, $P = .016$) were positive predictors of physical activity over 6 months. **Conclusions:** Commercially available physical activity apps have potential to support long-term engagement in physical activity. Social support, self-efficacy, and motivation (identified and introjected) are important predictors of long-term physical activity. Commercial physical activity apps should seek to more widely

incorporate features that target these psychological constructs to maximise effectiveness. Randomised controlled trials evaluating the capacity of commercial physical activity apps to support the initiation and maintenance of physical activity are warranted.

Introduction

Physical activity is important for physical and mental health, with benefits including decreasing the risk of cardiovascular disease, obesity, Type 2 diabetes, some types of cancer (colon and breast cancer), osteoporosis, depression, and anxiety (Rhodes, Janssen, Bredin, Warburton, & Bauman, 2017; Warburton, Nicol, & Bredin, 2006). To attain these benefits, the World Health Organisation recommends engaging in 150 minutes of moderate or 75 minutes of vigorous aerobic activity per week (World Health Organisation, 2020). However, globally almost a third of adults are insufficiently active, with inactivity most pervasive in high-income countries (Guthold, Stevens, Riley, & Bull, 2018). As such, physical inactivity is a leading modifiable risk factor for premature mortality worldwide (Guthold et al., 2018; World Health Organisation, 2020) and has an escalating economic burden (Ding et al., 2016). The development of strategies to promote physical activity engagement and reduce physical inactivity is a global public health priority.

Existing literature has identified psychological constructs that are embedded in many health behaviour change theories and have been consistently linked to physical activity engagement (Rhodes et al., 2017). In particular, social support is recognised as a critical driver of physical activity, as demonstrated by Farren, Zhang, Martin and Thomas (2017) who found that college students with higher levels of perceived social support for physical activity were more likely to meet physical activity guidelines. Self-efficacy is another important modifiable determinant of physical activity, and has been shown to play a central role in long-term adherence (Amireault, Godin, & Vézina-Im, 2013). For example, Janssen, Dugan, Karavolos, Lynch and Powell (2014) found that higher self-efficacy was linked to consistent engagement in physical activity over a 15-year period. Finally, motivation is a well-documented correlate of physical activity and has been extensively examined in the context of Self-determination Theory (Deci & Ryan, 1985). This theoretical framework

proposes a continuum of motivations for physical activity from autonomous (e.g., motivation derived from enjoyment or satisfaction) to controlled (e.g., motivation derived from obtaining rewards or avoiding punishment) (Deci & Ryan, 1985). Autonomous types of motivation are shown to facilitate greater physical activity across the lifespan (Brunet & Sabiston, 2011) and are a robust predictor of long-term engagement in physical activity (Teixeira, Carraça, Markland, Silva, & Ryan, 2012). Therefore, social support, self-efficacy and motivation are important to consider in the development of strategies to facilitate and maintain physical activity engagement over time.

Commercially available physical activity apps present novel prospects for physical activity promotion given their accessibility, convenience, cost-effectiveness, and widespread reach. Recent cross-sectional research has demonstrated an association between commercial app use and higher engagement in physical activity (Petersen, Kemps, Lewis, & Prichard, 2020a), including during the COVID-19 pandemic (Petersen, Kemps, Lewis, & Prichard, 2021). This research has further shown that commercial physical activity apps have the capacity to facilitate social support, and positively influence self-efficacy and autonomous types of motivation (Petersen, Kemps, Lewis, & Prichard, 2020b). These apps may, therefore, be a valuable tool in supporting sustained physical activity engagement (≥6 months; Murray et al., 2018), a frequently cited challenge in physical activity promotion (Amireault et al., 2013). Recent reviews have, however, indicated that there is a dearth of evidence on the long-term effectiveness of physical activity apps (>3months), particularly those that are commercially available (Petersen, Prichard, & Kemps, 2019; Romeo et al., 2019). One recent study reported that a commercial physical activity app ("Carrot Rewards") significantly increased physical activity (step counts) among initially inactive users over a year (Mitchell, Lau, White, & Faulkner, 2020). There is a clear need to further evaluate the capacity of commercial physical activity apps to promote longer term physical activity, especially given

that sustained engagement in physical activity is associated with superior health outcomes (Rhodes et al., 2017; Warburton et al., 2006).

There is growing consensus that to maximise the effectiveness of physical activity apps, an understanding is required of the value of the specific app features in supporting physical activity. Social features that facilitate supportive interactions with other users (app-specific communities) or connections to existing social networking platforms (e.g., Facebook) are common to many commercial physical activity apps (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018; Mollee, Middelweerd, Kurvers, & Klein, 2017). Cross-sectional evidence shows that the use of these social features is positively associated with physical activity engagement in the general population (Petersen et al., 2020a; Petersen et al., 2021). Existing social networking platforms are suggested to be particularly valuable given their potential to increase engagement with physical activity apps (Petersen et al., 2019); higher engagement has been consistently associated with enhanced app effectiveness (Schoeppe et al., 2016). Additionally, connecting with existing social networking platforms is positively associated with self-efficacy and autonomous types of motivation (Petersen et al., 2020b), both of which have been linked to prolonged engagement in physical activity (Amireault et al., 2013; Teixeira et al., 2012). To date, the role of social features of apps in supporting long-term engagement in physical activity is unknown.

Given the lack of evidence pertaining to long-term commercial app use and physical activity, this study aimed to examine the longitudinal associations between the use of commercial physical activity apps (and their social features) and engagement in physical activity over a 6-month period (duration indicative of behaviour maintenance and reduced risk of relapse to physical inactivity; Dishman, 1994; Murray et al., 2018). We also aimed to investigate the roles of social support, self-efficacy, and motivation in the longitudinal associations between commercial app use and physical activity.

Method

Participants

Participants were recruited using social networking platforms (e.g., Facebook, Instagram, and Twitter) and the University Discipline of Psychology's online research participation system. The participants were a subset of a larger sample of adults (n = 1432; Petersen et al., 2020a) who had completed assessments at 3 (n = 632) and/or 6 (n = 511) months following their initial participation (total sample for this study = 731). Ethical approval was obtained from the University's Social and Behavioural Research Committee (protocol no. 8232). All participants provided informed consent electronically.

Procedure

Data were collected between February and October 2019 using an online survey (Qualtrics). All participants completed an initial baseline assessment, and were invited to provide their email address to be contacted for follow-up assessments approximately 3 and 6 months later. The survey completed at each time-point was identical and incorporated the measures listed below in order of presentation (Appendix C). Participants had the opportunity to enter a draw to win one of five AUD25 shopping gift vouchers (at each of the 3 time points) in recognition of their time commitment.

Measures

Regular physical activity. Following Prichard and Tiggemann (2008), participants self-reported their regular physical activity by indicating the type, frequency, and duration of any physical activity/ sport they engaged in on a weekly basis. Total physical activity (min/week) was calculated by multiplying the frequency of each activity by its duration.

Current physical activity app use. Participants self-reported their current use of physical activity apps (apps that have the capacity to track or monitor physical activity or provide guided training or workouts) as per Petersen et al. (2020a). Those who reported using a physical activity app were invited to specify the name of the app they were currently using most frequently (main physical activity app; e.g., Strava), and their level of engagement with the app (number of times used per week).

Engagement with app-specific communities. Participants reported their engagement with the app-specific community of the main physical activity app following Petersen et al. (2020a). This included specifying on a 6-point Likert scale how often (from *never* (0) to *very often* (5)) they engaged with members of the app-specific community (e.g., family, close friends) by sharing physical activity posts, liking and/or providing positive comments on others' posts, receiving likes and/or positive comments, comparing their physical activity performance to others, and engaging in competitions. A composite score (ranging from 0-5) was calculated for the use of each specific feature (e.g., sharing) across the different members of the app-specific community (e.g., family, close friends) (Petersen et al., 2020a).

Engagement with existing social networking platforms. Engagement with existing social networking platforms was assessed by items from Petersen et al. (2020a). Participants reported on a 6-point Likert scale how frequently (from *never* (0) to *very often* (5)) they shared physical activity posts, liked and/or provided positive comments on others' posts, received likes and/or positive comments, and compared their physical activity performance to others' physical activity posts on Facebook, Instagram, or Twitter (plus the option to specify (an)other platform(s)). Again, a composite score (ranging from 0-5) was calculated for the use of each specific feature (e.g., sharing) across the different social networking platforms (e.g., Facebook, Instagram).

Perceived social support for physical activity. To assess perceived social support for physical activity, the 26-item Social Support for Exercise Behaviors Scale (Sallis, Grossman, Pinski, Patterson, & Nader, 1987) was administered. The measure incorporates two subscales to capture the support participants felt they had received for physical activity from friends and family. Each subscale consists of 13 items rated on a 5-point Likert scale ranging from 1 (*never*) to 5 (*very often*). A composite score was generated by averaging the 26 items (Sallis et al., 1987), with higher scores indicating greater perceived social support from family and friends. The internal reliability was high across all time points ($\alpha = .93$).

Perceived self-efficacy for physical activity. Perceived self-efficacy for physical activity was assessed by the Physical Activity Self-Efficacy Scale (Schwarzer & Renner, 2009). The scale consists of 5 items measuring participants' capacity to engage in physical activity in the presence of common barriers (e.g., tired, busy). Items are rated on a 4-point Likert scale from 1 (*very uncertain*) to 4 (*very certain*). The 5 items are averaged, with a higher score indicating greater perceived self-efficacy for physical activity. In the current study, the Cronbach alpha was .93 across time points.

Motivations for physical activity. Motivations for physical activity were measured by the 19-item Behavioral Regulation in Exercise Questionnaire-2 (BREQ-2) (Markland & Tobin, 2004). The BREQ-2 is based on Self-determination Theory. It incorporates five subscales which assess intrinsic motivation (4 items), identified regulation (4 items), introjected regulation (3 items), external regulation (4 items) and amotivation (4 items). Responses are made on a 5-point Likert Scale from 0 (*not true for me*) to 4 (*very true for me*), and a score for each motivation type is generated by averaging the representative items. In the present study, the internal reliability was high across all subscales at baseline ($\alpha = .82$-$.94$), 3 months ($\alpha = .85$-$.95$), and 6 months ($\alpha = .84$-$.95$).

Statistical Analysis

Missing data were handled using multiple imputation, assuming missing-at-random. Five imputed datasets were created, in line with recommendations by Schafer (1999). The results from the pooled datasets are presented.

Descriptive statistics were calculated for all variables. Generalised Estimating Equations (GEE) were used to examine associations between each time-varying predictor variable (e.g., commercial physical activity app use) and physical activity (min/week). This approach simultaneously analyses the relationships between the variables of the model at different time points (Twisk, 2013). GEE combines both the intra- and inter-individual relationships between the predictor and outcome variables into a single regression coefficient, and accounts for intra-individual correlations due to repeated measures over time. Two independent models were conducted in line with the study aims. Model 1 incorporated commercial physical activity app use, engagement with features of app-specific communities and existing social networking platforms, demographic variables (age, gender), and the time factor (baseline, 3-months, 6-months) (Aim 1). Model 2 repeated this approach but also incorporated psychological constructs (social support, self-efficacy, and motivation) (Aim 2). The GEE were conducted with an exchangeable correlation structure. All statistical analyses were performed with SPSS version 27 (IBM, Corp). Alpha was set at 0.05.

Results

Sample

Data from 731 participants (88% female) were included in the analyses (Table 1). Participants were predominately Caucasian (89.1%) and aged 18 to 74 years (M = 34.01, SD = 13.3). On average, participants engaged in 281 minutes of physical activity per week at baseline (SD = 218.6). There were no significant differences between participants retained in

the analyses and those lost to follow-up in relation to the variables of interest (physical activity, physical activity app use, social support, self-efficacy, and motivation).

Table 1

Sample characteristics

	Baseline (n = 731)	3 months (n = 632)	6 months (n = 511)
Physical activity (min/ week), *M (SD)*	281.0 (218.6)	258.1 (230.4)	276.1 (282.7)
Physical activity app use, *n* (%)	401 (54.9)	323 (51.1)	254 (49.7)
Psychological constructs, *M (SD)*			
Social support	1.8 (0.6)	1.8 (0.6)	1.8 (0.6)
Self-efficacy	2.7 (0.8)	2.6 (0.8)	2.6 (0.8)
Intrinsic motivation	3.7 (1.1)	3.7 (1.1)	3.5 (1.2)
Identified regulation	4.0 (0.9)	4.0 (0.9)	3.9 (0.9)
Introjected regulation	2.9 (1.2)	2.9 (1.2)	2.8 (1.2)
External regulation	1.6 (0.8)	1.6 (0.8)	1.6 (0.8)
Amotivation	1.4 (0.7)	1.5 (0.8)	1.4 (0.8)

Physical Activity App Use

Approximately half of the participants reported using a physical activity app at all time points (Table 1). There was relatively small intra-individual variation in app use over time, with few (23.0%) participants switching from use to non-use (or vice-versa). Similarly, users largely (77.0%) engaged with the same app across time, with Fitbit, Strava and Garmin the most used apps. At baseline, 60% of app users reported that the physical activity app they were using had an app-specific community, of which 40% reported using it, and this

remained consistent over the 6-month period. Most app users (88% to 93%) engaged with existing social networking platforms in relation to physical activity across the time points.

Longitudinal Analyses; Determining Predictors of Physical Activity (min/week) over Time

Table 2 presents the results of the GEE. Model 1 shows that physical activity app users engaged in significantly higher levels of physical activity than non-users over the 6-month period, reporting on average 59 minutes more of physical activity per week (B = 59.3, $P < .001$; see Figure 1). Among app users, sharing physical activity behaviour to existing social networking platforms was a significant positive predictor of physical activity engagement (B = 41.0, $P = .040$).

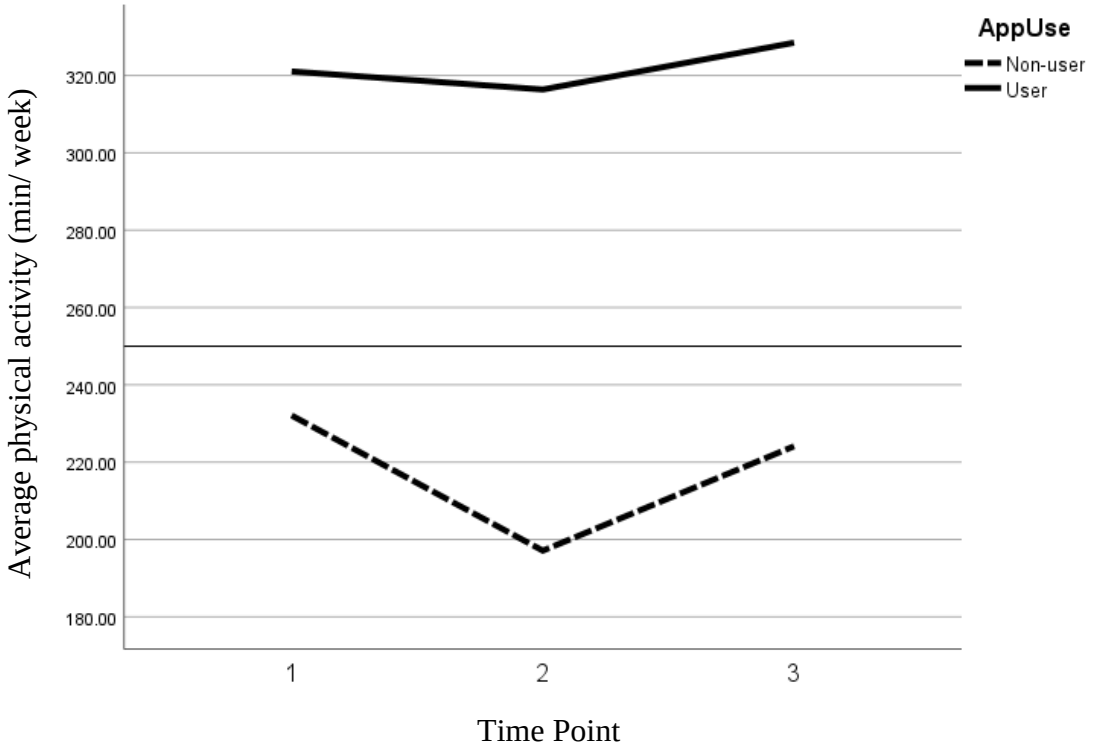

Figure 1. Longitudinal association between commercial physical activity app use and physical activity (min/ week).

In Model 2 with the inclusion of the psychological variables (see Table 2), identified regulation (B = 57.6, *P* < .001) emerged as the strongest predictor of physical activity over 6 months, followed by self-efficacy (B = 55.0, *P* < .001), social support (B = 46.3, *P* < .001), and introjected regulation (B = 13.6, *P* = .016). External regulation was a significant negative predictor of physical activity engagement (B = -24.2, *P* = .002). Physical activity app use (B = 18.0, *P* = .108) and sharing physical activity to existing social networking platforms (B = 11.0, *P* = .405) were no longer significant predictors of physical activity engagement. In both Models 1 and 2, there was no significant change in physical activity over time (B = -2.2, *P* = .672; B = 4.1, *P* = .410, respectively).

Table 2

GEE longitudinal analysis examining the predictors of physical activity (min/week) over time

	Model 1		Model 2	
Variables	B	95% CI	B	95% CI
Time	-2.2	[-12.2, 7.9]	4.1	[-5.6, 13.8]
Age	0.47	[-0.76, 1.7]	0.15	[-0.90, 1.2]
Gender (vs. male)	25.8	[-20.8, 72.4]	35.2	[-3.6, 74.0]
App User (vs. non-user)	59.3***	[35.5, 83.1]	18.0	[-4.0, 40.0]
App Communities				
Sharing physical activity	-10.3	[-34.3, 13.6]	-1.3	[-22.0, 19.3]
Providing encouragement	18.3	[-1.7, 38.3]	10.0	[-8.4, 28.5]
Receiving encouragement	-9.4	[-53.6, 34.7]	-13.1	[-42.6, 16.4]
Engagement in competitions	-21.0	[-55.1, 13.2]	-4.0	[-32.6, 24.7]
Engagement in comparisons	12.1	[-22.3, 46.5]	2.8	[-19.4, 25.0]
Existing social networking platforms				
Sharing physical activity posts	41.0*	[2.4, 79.3]	11.0	[-15.4, 37.0]
Providing encouragement	-1.8	[-21.3, 17.6]	1.5	[-16.6, 19.6]
Receiving encouragement	17.7	[-14.7, 50.2]	4.8	[-14.4, 24.0]
Engagement in comparisons	-22.7	[-46.8, 1.3]	-13.3	[-34.4, 7.8]
Psychological constructs				
Social support			46.3***	[25.5, 67.0]
Self-efficacy			55.0***	[38.7, 71.2]
Intrinsic motivation			5.5	[-10.2, 21.3]
Identified regulation			57.6***	[40.0, 75.3]
Introjected regulation			13.6*	[2.5, 24.7]
External regulation			-24.2**	[-39.5, -8.8]
Amotivation			-3.8	[-21.0, 13.2]

*$P < .05$; **$P < .01$; ***$P < .001$.

Discussion

The present study aimed to examine the capacity of commercially available physical activity apps (and social features) to support longer term engagement in physical activity. We also sought to gain insight into the role of social support, self-efficacy and motivation, in the longitudinal associations between commercial app use and physical activity.

Commercial physical activity app use predicted higher physical activity engagement over 6 months, with app users engaging in an average of 59 minutes more physical activity per week than non-users. Existing research has demonstrated cross-sectional associations between commercial app use and higher levels of physical activity (Petersen et al., 2020a; Petersen et al., 2021). As an important extension, the present study indicates that commercial physical activity apps are beneficial in supporting longer-term physical activity engagement. This finding makes a valuable contribution to the extant literature given: (1) the dearth of evidence pertaining to the long-term effectiveness of commercial physical activity apps, and (2) the growing need to ascertain effective strategies to support prolonged physical activity engagement, critical to facilitating superior physical and mental health outcomes (Rhodes et al., 2017; Warburton et al., 2006).

Participants largely reported continued use of apps that function to track or monitor physical activity behaviours (Fitbit, Garmin and Strava). Self-monitoring is suggested to facilitate habit formation shown to aid long-term physical activity maintenance (Lally & Gardner, 2013). Therefore, apps such as Fitbit, Garmin and Strava may be most valuable in supporting prolonged physical activity. These apps are widely accessible, inexpensive, and allow for many different types of physical activity to be tracked, logged and self-monitored, and therefore, could be useful across different age groups, fitness levels and abilities. As the current sample of app users were all physically active, research should now evaluate the

capacity of these apps to support the initiation and maintenance of physical activity among inactive populations.

Our findings further indicate that app users who shared physical activity to existing social networking platforms engaged in more physical activity over time than those who did not. This is consistent with evidence indicating that sharing physical activity to social networking platforms is positively associated with self-efficacy and autonomous types of motivation (Petersen et al., 2020b), psychological constructs that are consistent predictors of prolonged physical activity engagement (Amireault et al., 2013; Janssen et al., 2014; Teixeira et al., 2012). Similarly, Oeldorf-Hirsch, High and Christensen (2019) reported that sharing tracked health information to social networking platforms (e.g., physical activity, sleep, calories) fosters the provision of support which has long been recognised as a precursor to self-efficacy, the most reliable determinant of physical activity engagement (Choi, Lee, Lee, Kang, & Choi, 2017). Recent research further suggests that sharing fitness posts to social networking platforms promotes accountability (Liu & Kashian, 2021). Accountability is critical to supporting maintained engagement in health behaviours by fostering motivation to progress health goals (Newman, Lauterbach, Munson, Resnick, & Morris, 2011). This is the first study to demonstrate the role of existing social networking platforms in supporting longer term engagement in physical activity among app users, adding to the accumulating evidence about the value of these platforms in promoting positive health behaviours.

Although commercial physical activity app use predicted physical activity over 6 months, after the inclusion of psychological constructs (social support, self-efficacy, motivation) this relationship was no longer significant. Instead, social support, self-efficacy (an individual's beliefs pertaining to their ability to perform physical activity) and identified regulation (personal value placed on the outcomes of physical activity) emerged as the strongest positive predictors of physical activity over time. This finding lends further support

to the importance of self-efficacy and autonomous types of motivation in promoting prolonged engagement in physical activity (Amireault et al., 2013; Teixeira et al., 2012). It also suggests that these psychological constructs may have played an important underlying role in the initial relationship that emerged between commercial physical activity app use and long-term physical activity. This is consistent with existing cross-sectional research indicating that social support, self-efficacy and autonomous types of motivation mediate the positive relationship between commercial app use and physical activity (Petersen et al., 2020b). Physical activity apps that target social support, self-efficacy and autonomous types of motivation may be most beneficial to supporting an active lifestyle, and these psychological constructs should, therefore, be considered in the development of these apps. For example, the adaptive capabilities of physical activity apps could be harnessed to tailor app content according to user characteristics (i.e., social support, self-efficacy, and motivation), and maximise the capacity of apps to promote physical activity engagement.

Interestingly, there was very little intra-individual variation in app use, and most users (77.0%) engaged with the same app across time. This conflicts with recent commercial research reporting that the average 90-day and annual retention rate of fitness apps is relatively low (31% and 18%, respectively) (Apptentive, 2021). Although the timeframe over which users had been previously engaging with the apps in the present study is unknown, it is possible that these were established users who had already found an app they were satisfied with. Additionally, most users engaged with apps that incorporated the functionality to automatically track or monitor behaviour, reducing user burden (e.g., manually logging behaviour) and potentially facilitating continued use of such apps. This fits with evidence indicating that ease of use is positively associated with intentions to continue using fitness apps (Zhang & Xu, 2020). To date, there is limited evidence pertaining to user characteristics that determine continued use of physical activity apps. One recent study does, however,

suggest that exercise identity (i.e., the extent to which one identifies oneself as an "exerciser"; Anderson & Cychosz, 1994) may play an important role in the use of fitness apps, with those with higher exercise identity potentially seeking out, and continuing to engage with this technology to reaffirm their identity (Barkley, Lepp, Santo, Glickman, & Dowdell, 2020). Future research could further examine other user characteristics that may predict continued physical activity app use, for example, trait competitiveness, in line with evidence suggesting that those with competitive tendencies may benefit most from such apps (Petersen et al., 2020b).

The present study has some important practical implications. First, the findings suggest that commercial physical activity apps are valuable in supporting longer-term engagement in physical activity, important to attaining the health benefits associated with being active. From a public health perspective, these widely accessible apps could be harnessed for physical activity promotion to support active lifestyles and optimise population-level health outcomes. Second, physical activity app users should be encouraged to share their physical activity behaviour to existing social networking platforms, given this was shown to be beneficial in promoting maintained physical activity engagement. Finally, social support, self-efficacy, and autonomous types of motivation are fundamental to supporting prolonged physical activity engagement. Physical activity apps should therefore incorporate features and functionalities that target these psychological constructs to maximise the benefits of such apps.

The present study has several strengths. Specifically, it is the first to use a longitudinal design to examine the capacity of commercial physical activity apps to support longer term physical activity engagement and provides an important contribution to this burgeoning field of research. The study also recruited a relatively large sample. Nevertheless, there are also some limitations that should be acknowledged. In particular, the sample comprised largely of

women who engaged in high levels of physical activity over time. This may limit the generalisability of the findings (e.g., prolonged app use) to the population more broadly. Additionally, physical activity behaviour and app use were self-reported and thus may have been subject to reporting inaccuracies. Future research would benefit from using accelerometer-derived measures of physical activity (in addition to self-report measures) and objective assessments of app use (e.g., Google Analytics). Finally, given the observational nature of this study, causality cannot be assumed. Experimental intervention research is now necessary to determine whether commercial physical activity apps have the potential to support sustained positive changes in physical activity engagement and the constructs associated with physical activity (e.g., self-efficacy, social support, autonomous types of motivation).

The present study provides novel insights into the role of commercial physical activity apps in supporting longer-term physical activity. The findings show that commercial physical activity apps have potential to promote prolonged physical activity engagement. Social support, self-efficacy, and autonomous types of motivation are, however, the most important predictors of long-term physical activity, and should therefore be considered in the development of physical activity apps. Future experimental research should evaluate the capacity of commercial physical activity apps to support the initiation and maintenance of physical activity engagement.

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CHAPTER 6: STUDY 5

Promoting physical activity during the COVID-19 lockdown in Australia: The roles of psychological predictors and commercial physical activity apps

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Abstract

Purpose: Physical activity confers many physical and mental health benefits. Thus, it is of great concern that the COVID-19 lockdown has adversely impacted engagement in physical activity. There is a need to understand the factors linked to physical activity during COVID-19 as this will be fundamental to the development of innovative approaches to support engagement in physical activity during a pandemic. This study aimed to ascertain the psychological and mental health predictors of physical activity during the COVID-19 lockdown. We also examined the value of harnessing commercial physical activity apps to facilitate physical activity during a pandemic. **Method:** A nationwide online survey was completed by 408 Australian adults (M_{age} = 35.7 ± 13.9 years, 86.0% female) following the initial COVID-19 lockdown (April/May 2020). The survey incorporated measures that retrospectively assessed physical activity (and perceived changes in physical activity behaviour), psychological constructs (social support, self-efficacy, motivations), mental health, and engagement with commercial physical activity apps during the lockdown. **Results:** Over half of participants (53.4%) reported a reduction in physical activity during the initial COVID-19 lockdown, with markedly fewer (23.8%) reporting an increase in physical activity. App use (β = .09, *P* = .027), social support (β = .10, *P* = .021), self-efficacy (β = .42, *P* < .001), and identified regulation (β = .25, *P* < .001) emerged as important predictors of physical activity engagement (min/week). Self-efficacy (OR = 4.2, *P* < .001) was also associated with a greater likelihood of perceived positive changes (increases) in physical activity. The relationship between app use and physical activity was mediated by self-efficacy (β = 0.10 [0.06, 0.15]) and identified regulation (β = 0.09 [0.04, 0.15]); self-efficacy (β = 0.15, [0.09, 0.21]) also mediated the relationship between app use and positive changes in physical activity. **Conclusions:** It is imperative that interventions targeted at increasing social support, self-efficacy, and autonomous types of motivation are developed and utilised

to support engagement in physical activity during a pandemic. Commercial physical activity apps demonstrate the potential to mitigate reductions in physical activity during a pandemic, and thus the use of these apps should be encouraged.

Introduction

Physical inactivity is a leading modifiable risk factor for morbidity and premature mortality globally (World Health Organisation, 2020). There is robust evidence about the many physical and mental health benefits of physical activity, including a reduced risk of chronic disease, depression, and anxiety (Warburton, Nicol, & Bredin, 2006). Nevertheless, over half of the Australian adult population is insufficiently active (they do not meet current guidelines) (Australian Institute of Health and Welfare, 2020). Concerningly, COVID-19 and associated lockdown periods may have further reduced engagement in physical activity due to closure of indoor and outdoor sporting facilities, cancellation of sporting competitions, isolation, social distancing, and travel restrictions. Indeed, reductions in physical activity during COVID-19 lockdowns have already been reported in Australia (Stanton et al., 2020) and worldwide (López-Bueno et al., 2020; Maugeri et al., 2020; Meyer et al., 2020). Therefore, it is imperative that innovative approaches are developed to support engagement in physical activity during a pandemic such as COVID-19. However, this first requires an understanding of the factors that are linked to physical activity during a pandemic.

A small body of research has begun to explore some psychological correlates of physical activity during COVID-19 including personality traits (e.g., extraversion), goal striving, strategic planning, exercise identity, perceived behavioural control, self-efficacy, and attitudes (Chirico et al., 2020; Kaushal, Keith, Aguiñaga, & Hagger, 2020; Rhodes, Liu, Lithopoulos, Zhang, & Garcia-Barrera, 2020; Teran-Escobar et al., 2021). Specifically, using a single item, Teran-Escobar et al. (2021) examined the role of self-efficacy, and found that it was not a significant predictor of physical activity during the COVID-19 lockdown. Another important psychological correlate is social support. Like self-efficacy, social support is among the strongest predictors of physical activity (during non-pandemic times) and is similarly underpinned by many behaviour change theories (Rhodes, Janssen, Bredin,

Warburton, & Bauman, 2017; Trost, Owen, Bauman, Sallis, & Brown, 2002). Motivation has also been consistently linked to physical activity (Teixeira, Carraça, Markland, Silva, & Ryan, 2012), and is commonly examined in relation to Self-determination Theory (SDT) (Deci & Ryan, 1985). This theory distinguishes autonomous forms of motivation, intrinsic motivation (enjoyment derived from physical activity) and identified regulation (personal value placed on the outcomes of physical activity), and controlling forms of motivation, introjected regulation (internal obligation to carry out activity, feelings of guilt or anxiety) and external regulation (seeking external reinforcements or avoiding punishments) (Deci & Ryan, 1985). Autonomous types of motivation are the strongest predictor of long-term engagement in physical activity (Teixeira et al., 2012); this is particularly important in the context of a pandemic which may lead to profound changes to opportunities for physical activity for a prolonged period. Recent research has demonstrated that autonomous types of motivation play an important role in predicting physical activity intentions (Chirico et al., 2020; Kaushal et al., 2020) and habits (Kaushal et al., 2020) during COVID-19. Therefore, the role of motivation in addition to those of self-efficacy and social support should be considered in determining the psychological constructs that are important in facilitating physical activity behaviour during a pandemic.

Mental health is another factor that has been linked to physical activity engagement (Mikkelsen, Stojanovska, Polenakovic, Bosevski, & Apostolopoulos, 2017), and is particularly pertinent in the context of a pandemic. Evidence exists to suggest a bi-directional relationship between physical activity and mental health, such that physical activity influences mental health, and reciprocally, mental health influences physical activity levels (Gucciardi et al., 2020; Hiles, Lamers, Milaneschi, & Penninx, 2017). Research during COVID-19 has thus far focused on the former direction. For example, Stanton et al. (2020) reported that reductions in physical activity during COVID-19 were linked to more severe

depression, anxiety, and stress symptoms in a sample of Australian adults. Similarly, Schuch et al. (2020) identified that physical activity (≥30min/day moderate-vigorous PA or ≥15min day vigorous PA) was associated with a reduced likelihood of depression and anxiety among Brazilian adults. Because of the reciprocal relationship between mental health and physical activity observed during non-pandemic times (Gucciardi et al., 2020; Hiles et al., 2017), it is necessary to consider mental health as a factor that has the potential to affect physical activity behaviour during a pandemic. Therefore, the present study examined the role of mental health alongside the aforementioned psychological constructs in facilitating physical activity during the COVID-19 lockdown in Australia to gain a more comprehensive insight into the promotion of physical activity during a pandemic.

Harnessing digital technology provides a promising approach to promote engagement in physical activity during a pandemic. Technology such as commercial physical activity apps (e.g., Strava, Fitbit) can be used within the home, and are accessible and affordable. Commercial physical activity apps also hold great potential, given their acceptability by the general population, and ever-increasing availability (Grand View Research, 2017; Petersen, Kemps, Lewis, & Prichard, 2020a). In addition, many commercial physical activity apps incorporate social components that facilitate connections with other app users (app-specific communities) or existing social networking platforms (e.g., Facebook) (Bondaronek, Alkhaldi, Slee, Hamilton, & Murray, 2018; Mollee, Middelweerd, Kurvers, & Klein, 2017); these are particularly valuable during a pandemic when face-to-face social support is restricted. It is, therefore, perhaps not surprising that commercial physical activity apps were immensely popular during COVID-19, with reports that downloads of such apps increased by almost fifty percent during the first half of 2020 (Ang, 2020). Importantly, a study conducted in the U.S. showed that physical activity apps were beneficial in preventing declines in physical activity during the COVID-19 lockdown (Yang & Koenigstorfer, 2020). However, it

is currently unclear how exactly these apps promote engagement in physical activity during a pandemic. Previous research (during non-pandemic times) has shown that the use of commercial physical activity apps is linked to higher physical activity engagement, due to their capacity to facilitate social support, and positively influence motivation and beliefs in one's ability to perform physical activity (self-efficacy) (Petersen, Kemps, Lewis, & Prichard, 2020b). There is a clear need to further validate the value of engaging with commercial physical activity apps during the COVID-19 pandemic and resulting lockdowns. This includes examining the mechanisms underlying the purported relationship between app use and physical activity during a pandemic lockdown, with a specific focus on social support, self-efficacy, and motivations.

The present study aimed to provide insight into physical activity during the initial COVID-19 lockdown in Australia (April/May 2020). This included ascertaining the psychological (social support, self-efficacy, motivations) and mental health (depression, anxiety, stress) predictors of physical activity during the COVID-19 lockdown. We also investigated the role of commercial physical activity apps (and their social features) in facilitating physical activity during the COVID-19 lockdown. Finally, we sought to determine whether the relationship between commercial physical activity app use and physical activity during the lockdown was mediated by psychological constructs.

Method

Design and Sample

The study used an observational design. Participants were a subset of a larger sample (n = 1432; Petersen et al., 2020a) contacted via email and invited to respond to an online survey about their physical activity behaviour during the initial COVID-19 lockdown in Australia (April/May 2020). A total of 471 Australian adults responded, of whom 412 provided complete data on the variables of interest. Data of four participants were excluded

due to implausible physical activity values (>1000 min/week). This resulted in a final sample of 408. All participants provided informed consent electronically. Ethical approval was granted by the University's Social and Behavioural Research Ethics Committee (protocol no. 8232).

Procedure

Data collection occurred from June to July 2020 using an online survey conducted through the Qualtrics platform. The survey incorporated measures that retrospectively assessed participants' physical activity (behaviour and beliefs), mental health, and commercial physical activity app use during the COVID-19 lockdown in Australia (Appendix F). Participants were provided with the opportunity to enter a raffle to win one of five AUD25 gift vouchers in recognition of their time commitment.

Measures

Demographics. Participants reported their age, gender, postcode, height, and weight (to determine BMI (kg/m^2)).

Physical activity. Participants retrospectively self-reported the physical activities they engaged in during the COVID-19 lockdown. Using an open-ended response format, they reported the specific type (e.g., running, walking), and frequency and duration (mins) per week of each activity. Total physical activity (min/week) was calculated by multiplying the frequency of each activity by its duration (Prichard & Tiggemann, 2008).

Perceived change in physical activity. Participants indicated whether they had changed their physical activity behaviours during the lockdown compared to prior to COVID-19. Specifically, following Stanton et al. (2020) participants selected from six possible categorical response options ranging from much more active than usual to ceased physical activity altogether, to indicate their change in physical activity. Responses were categorised

as increased (much more or little more), no change (maintained), or decreased physical activity (little less, much less or ceased activity).

Social support. The Social Support for Exercise Behaviors Scale was used to assess perceived social support for physical activity (Sallis, Grossman, Pinski, Patterson, & Nader, 1987). Participants reported the perceived level of support received from family (13 items) and friends (13 items) during the COVID-19 lockdown on a 5-point Likert scale from 1 (*never*) to 5 (*very often*). An average score was generated from the 26 items (Sallis et al., 1987). The internal reliability in the present sample was high (α = .90).

Physical activity self-efficacy. Perceived self-efficacy for physical activity was measured using The Physical Activity Self-efficacy Scale (Schwarzer & Renner, 2009). The scale comprises 5 items that determine how certain, from 1 (*very uncertain*) to 4 (*very certain*) an individual is that they could exercise in the presence of barriers (e.g., tired, depressed) during the COVID-19 lockdown. A composite score was generated by averaging the 5 items. In the present study, the internal reliability was high (α = .95).

Behavioural regulation motives. Motivations for physical activity during the COVID-19 lockdown was assessed using the 19-item Behavioral Regulation in Exercise Questionnaire (BREQ-2) (Markland & Tobin, 2004). The BREQ-2 consists of 5 subscales that assess motivation types from Self-determination Theory (intrinsic motivation, identified regulation, introjected regulation, external regulation and amotivation). Items are rated on a 5-point Likert Scale from 0 (*not true for me*) to 4 (*very true for me*), and a score for each motivation type is generated by averaging the representative items. The reliability of the subscales ranged from α = .83 for external regulation to α = .95 for intrinsic motivation.

Mental health. The Depression, Anxiety and Stress Scales (DASS-21) (Lovibond & Lovibond, 1995a) were used to measure mental health during the COVID-19 lockdown. The measure consists of 21 items, comprising 3 subscales (each 7 items) assessing depression,

anxiety, and stress. Items are rated on a 4-point Likert Scale from 0 (*Did not apply to me*) to 3 (*Applied to me very much or most of the time*). A score for each subscale was calculated by summing the representative items (scores ranging from 0 to 21) (Lovibond & Lovibond, 1995a). The generated scores were interpreted according to the DASS sub-scale severity ratings (normal to extremely severe) suggested for Australia (Lovibond & Lovibond, 1995b). The reliability for each subscale was high; depression ($\alpha = .93$), anxiety ($\alpha = .86$), and stress ($\alpha = .89$).

Use of commercial physical activity apps. Engagement with commercial physical activity apps during the COVID-19 lockdown was assessed using items consistent with Petersen et al. (2020a). Specifically, participants reported if they had used a physical activity app (app that has the capacity to track/monitor physical activity or provide guided training/workouts) during the COVID-19 lockdown. Those who reported using a physical activity app were asked to specify the name of the app (e.g., Fitbit) and level of engagement with the app (times/week).

Engagement with app-specific communities. Engagement with the app-specific community of the main physical activity app used during the COVID-19 lockdown was measured following Petersen et al. (2020a). Using a 6-point Likert scale (from 0 (*never*) to 5 (*very often*)), participants indicated how often they engaged with various members of the app community (e.g., partner, family, close friends) by sharing physical activity posts, liking and/or providing positive comments on others' posts, receiving likes and/or positive comments, comparing their physical activity performance to others, and engaging in competitions. A composite score was generated for the use of each feature of the app-specific community (e.g., sharing) across the various networks (e.g., family, friends) (Petersen et al., 2020a).

Engagement with existing social networking platforms. Participants reported their physical activity related use of existing social networking platforms during the COVID-19 lockdown using a series of Likert scales (Petersen et al., 2020a). Specifically, participants indicated how often (ranging from *never* (0) to *very often* (5)) they engaged with features (sharing physical activity posts, liking and/or providing positive comments on others' posts, receiving likes and/or positive comments, and engaging in comparisons) of platforms such as Facebook, Instagram, and Twitter during the COVID-19 lockdown. A composite score was generated for the use of each feature (e.g., sharing) across the different social networking platforms (Petersen et al., 2020a).

Statistical Analysis

All statistical analyses were performed with SPSS version 25 (IBM, Corp) and Mplus version 8. Normality of the data was assessed, and variables that were not normally distributed were log-transformed. Skewness (range -0.55 to 1.5) and kurtosis values (range -1.1 to 2.0) were acceptable after transformation (Kline, 2005). Descriptive statistics were calculated for all variables. Preliminary analyses were then conducted to explore the relationships between physical activity (min/week and perceived change in physical activity), commercial physical activity app use, psychological constructs (social support, self-efficacy, and motivations), and mental health. The following analyses were conducted to further address the aims of this study.

First, to determine the predictors of physical activity and perceived changes in physical activity behaviour during the COVID-19 lockdown, a multiple linear regression and ordinal logistic regression were conducted, respectively. Both regression models incorporated psychological constructs (social support, self-efficacy, motivations), mental health and commercial physical activity app use, and controlled for demographic variables (age, gender, BMI, location). All variables were entered into the regression models simultaneously.

Dummy variables were created for multilevel categorical variables (age, BMI, location). Assumptions for the linear regression analysis were checked, specifically, assumptions of independence of observations (Durbin-Watson statistic of 2.1), linearity and homoscedasticity (visual inspection of standardized residuals vs fitted values plot), normality (visual inspection of Q-Q plot), multicollinearity (Variance inflation factor < 10 and tolerance value > 0.10), and undue influence (Cook's Distance max. value < 1). In relation to the ordinal logistic regression, the proportional odds assumption was checked by conducting the test of parallel lines ($P > .05$).

Second, path analyses were conducted in Mplus to assess statistical mediations among physical activity app use (independent variable; user vs non-user), psychological constructs (social support, self-efficacy, motivations), and physical activity (dependent variable; min/week) (Model 1) and perceived change in physical activity (dependent variable; increased, no change, decreased) (Model 2). Both models controlled for demographic variables (age, gender, BMI and location). They were estimated using maximum-likelihood estimation with robust standard errors (MLR) as it is robust to non-normality (untransformed values were used for ease of interpretation) and suitable for use with ordinal data. However, bootstrapping is currently unavailable with MLR, and thus, the models were re-estimated with the maximum likelihood estimation (ML), 5000 bootstrap samples were requested to calculate 95% bias corrected confidence intervals. The parameter estimates and significance levels were no different between the two estimation methods, and therefore, in line with recommendations (Preacher & Hayes, 2008) for testing mediation, the 95% bias corrected confidence intervals were examined for statistical significance. Mediation was indicated by 95% confidence intervals for the indirect effects that excluded zero. Goodness-of-fit statistics are not reported as our aim was to estimate specific effects (i.e., direct and mediation) of app use on physical activity rather than the fit of the whole model. Missing data (< 5%) were

handled with Full Information Maximum Likelihood (FIML), a robust strategy which estimates model parameters using all available data.

Results

Sample

The sample comprised of 408 participants. Table 1 presents the sample characteristics. Participants ranged in age from 18 to 74 years (*M* = 35.7 years, *SD* = 13.9) and were predominately female (86.0%). Almost half of the participants were located in South Australia or Victoria during the April/May COVID-19 lockdown; however, all Australian states and territories were represented in the sample. The mean body mass index (BMI) of the sample was 26.8 kg/m^2 (*SD* = 7.2) with almost half (47.5%) of participants reporting a BMI of 25 kg/m^2 or higher. On average, the sample engaged in 229 min of physical activity per week (*SD* = 210.2). A large proportion of participants (53.4%) reported a decrease in physical activity during the COVID-19 lockdown, while 23.8% reported an increase and 22.8% reported no change. The main types of physical activity participants reported engaging in during the COVID-19 lockdown were walking (43.5%), running (19.0%), home workouts (16.1%), yoga/Pilates (6.0%), cycling (5.6%), and strength training (3.1%). As shown in Table 1, physical activity (min/week) during the lockdown differed significantly according to age, BMI, and location.

Table 1

Sample characteristics (n = 408)

Characteristic	Overall, *n* (%)	Physical activity (min/ week)	*P* value	Perceived Physical activity, *n* (%)			*P* value
				Decrease	No change	Increase	
Age (years)							
18-30	184 (45.1)	194.7 (191.6)	.011	108 (58.7)	31 (16.8)	45 (24.5)	.087
>30-50	150 (36.8)	243.7 (215.2)		70 (46.7)	44 (29.3)	36 (24.0)	
>50	73 (17.9)	284.8 (232.0)		40 (54.8)	17 (23.3)	16 (21.9)	
Gender							
Female	351 (86.0)	232.6 (209.6)	.448	187 (53.3)	79 (22.5)	85 (24.2)	.688
Male	50 (12.2)	213.7 (215.7)		25 (50.0)	14 (28.0)	11 (22.0)	
BMI (kg/ m^2)							
Underweight (BMI <18.5)	10 (2.5)	118.2 (196.0)	<.001	6 (60.0)	3 (30.0)	1 (10.0)	.326
Normal weight (BMI 18.5-24.9)	185 (45.3)	248.3 (201.0)		95 (51.4)	47 (25.4)	43 (23.2)	
Overweight (BMI 25-29.9)	100 (24.5)	274.6 (216.0)		47 (47.0)	25 (25.0)	28 (28.0)	
Obese (BMI >30)	94 (23.0)	147.6 (182.8)		57 (60.6)	14 (14.9)	23 (24.5)	
State or territory							
SA	124 (30.4)	195.7 (208.3)	.034	75 (60.5)	25 (20.2)	24 (19.4)	.154
VIC	77 (18.9)	288.8 (219.2)		35 (45.5)	20 (25.9)	22 (28.6)	
QLD	62 (15.2)	198.5 (173.0)		32 (51.6)	12 (19.4)	18 (29.0)	
NSW	58 (14.2)	251.3 (211.9)		26 (44.8)	21 (36.2)	11 (19.0)	
WA	33 (8.1)	252.8 (198.4)		18 (54.5)	8 (24.2)	7 (21.2)	
ACT	24 (5.9)	223.0 (249.8)		17 (70.8)	3 (12.5)	4 (16.7)	
TAS	17 (4.2)	174.1 (186.1)		9 (53.0)	3 (17.6)	5 (29.4)	
NT	8 (2.0)	336.8 (270.3)		4 (50.0)	0 (0.0)	4 (50.0)	

Approximately half (51.2%, *n* = 209) of the sample used a commercial physical activity app during the COVID-19 lockdown. The most frequently used apps were Strava (23.0%), Fitbit (16.3%), and Garmin (10.0%). Participants largely reported using their apps seven times per week (35.0%), followed by 5 times (13.4%) and 3 times per week (13.0%). Among app users, 54.1% (*n* = 113) reported that the physical activity app they were currently using had an app-specific community, and of these 54.9% (*n* = 62) reported engaging with the community. Additionally, most app users (82.8%) engaged with existing social networking platforms in relation to physical activity.

Preliminary Analyses

Associations between Physical Activity, Psychological Constructs, and Mental Health

Correlations between physical activity (min/week), perceived change in physical activity (increase, no change, decrease), psychological constructs and mental health are presented in Table 2. Social support, self-efficacy, and autonomous types of motivation (intrinsic motivation and identified regulation) were significantly positively associated with physical activity and perceived change in physical activity. Amotivation, depression, anxiety, and stress were significantly negatively associated with physical activity and perceived change in physical activity.

Table 2

Correlations between physical activity (min/week), perceived change in physical activity, psychological constructs, and mental health.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Physical activity	1.0											
2. Perceived change in physical activity[a]	.43**	1.0										
3. Social support	.39**	.19**	1.0									
4. Self-efficacy	.64**	.50**	.26**	1.0								
5. BREQ-2: Intrinsic motivation	.56**	.31**	.44**	.54**	1.0							
6. BREQ-2: Identified regulation	.64**	.28**	.43**	.56**	.77**	1.0						
7. BREQ-2: Introjected regulation	.09	-.02	.23**	-.10*	.09	.30**	1.0					
8. BREQ-2: External regulation	-.06	-.03	.21**	-.17**	-.08	-.04	.34**	1.0				
9. BREQ-2: Amotivation	-.44**	-.21**	-.18**	-.39**	-.50**	-.53**	-.08	.28**	1.0			
10. DASS-21: Depression	-.27**	-.20**	-.19**	-.45**	-.41**	-.30**	.21**	.25**	.36**	1.0		
11. DASS-21: Anxiety	-.17**	-.11*	-.06	-.35**	-22**	-.19**	.20**	.24**	.29**	.66**	1.0	
12. DASS-21: Stress	-.18**	-.12*	-.03	-.44**	-.26**	-.16**	.25**	.28**	.32**	.71**	.72**	1.0
Mean	-	-	1.6	2.5	3.4	3.6	2.7	1.5	1.4	6.1	3.5	7.1
SD	-	-	0.6	0.9	1.3	1.1	1.2	0.7	0.8	5.8	4.1	5.2
IQR	-	-	1.1-1.9	1.8-3.2	2.5-4.5	3.0-4.5	1.7-3.6	1.0-1.7	1.0-1.7	1.2-9.0	0.0-5.0	3.0-11.0

**$P = .01$, *$P < .05$.

[a] Spearman rank-order correlation coefficient

Physical Activity and Physical Activity App Use

Commercial physical activity app users (n = 209) reported engaging in significantly more physical activity (M = 297.6 min/week, SD = 208.2) than non-users (M = 156.6, SD = 187.1), $t(406) = 8.4$, $P < .001$, $d = 0.71$. In addition, perceived change in physical activity also significantly varied by app use, ($\chi^2(2) = 22.1$, $P < .001$), such that a higher proportion of app users (31.6%) reported increased physical activity during the lockdown in comparison to non-users (15.6%). By contrast, a higher proportion of non-users (64.8%) reported a reduction in physical activity compared to app users (42.6%). Engagement with app-specific communities and social networking platforms was not linked to physical activity ($t(111) = 1.1$, $P = .282$, $d = 0.04$, $t(207) = 0.8$, $P = .432$, $d = 0.19$, respectively) nor to perceived change in physical activity ($\chi^2(2) = 2.7$, $P = .251$, $\chi^2(2) = 1.8$, $P = .407$, respectively). However, receiving encouragement ($r = .31$, $P < .05$) and engagement in competitions ($r = .26$, $P < .05$) was significantly positively correlated with physical activity in the context of app-specific communities, whereas sharing physical activity posts on existing social networking platforms ($r = .24$, $P = .01$) was associated with higher engagement in physical activity during the lockdown.

Significantly higher social support ($t(406) = 6.6$, $P < .001$, $d = 0.7$) and self-efficacy ($t(406) = 6.9$, $P < .001$, $d = 0.7$) was reported by app users (relative to non-users). They also reported significantly higher intrinsic motivation ($t(406) = 7.9$, $P < .001$, $d = 0.8$) and identified regulation ($t(406) = 7.9$, $P < .001$, $d = 0.7$), and lower amotivation ($t(406) = 5.7$, $P < .001$, $d = 0.7$) in comparison to non-users.

Regression Analyses; Determining Overall Predictors of Physical Activity and Perceived Change in Physical Activity during the COVID-19 Lockdown

Results of the multiple regression analysis are presented in Table 3. The regression model accounted for 58.8% of the variance in physical activity during the COVID-19

lockdown (R^2 = 0.588) and was significant, $F(24, 357) = 21.2$, $P < .001$. After controlling for age, gender, BMI, and location the following variables were significant positive predictors of physical activity: app use (β = .09, $P = .027$), social support (β = .10, $P = .021$), self-efficacy (β = .42, $P < .001$), and identified regulation (β = .25, $P < .001$). Amotivation was a significant negative predictor of physical activity (β = -.13, $P = .005$).

Table 3

Multiple regression analysis examining the predictors of physical activity (min/week) during the COVID-19 lockdown

Variable	β	*P* value	95% CI
Age (years) (18-30 is ref)			
>30-50	.07	.105	[-0.01,0.15]
>50	.07	.103	[-0.01,0.15]
Gender			
Female (vs. Male)	.04	.262	[-0.03,0.11]
Location (SA is ref)			
NSW	.03	.455	[-0.05,0.11]
ACT	.04	.219	[-0.03,0.12]
VIC	.06	.118	[-0.02,0.14]
QLD	-.20	.543	[-0.10,0.05]
TAS	.006	.857	[-0.06,0.08]
NT	.03	.437	[-0.04,0.09]
WA	.05	.141	[-0.02,0.13]
BMI (kg/m^2) (normal weight 18.5-24.9 is ref)			
Underweight (<18.5)	-.04	.299	[-0.11,0.03]
Overweight (25-29.9)	.02	.504	[-0.05,0.10]
Obese (>30)	-.08	.052	[-0.16,0.001]
Psychological constructs			
Social support	.10	.021	[0.01,0.18]
Self-efficacy	.42	<.001	[0.32,0.51]
Intrinsic motivation	.03	.666	[-0.09,0.14]

Identified regulation	.25	<.001	[0.12,0.38]
Introjected regulation	-.02	.554	[-0.11,0.06]
External regulation	.05	.269	[-0.03,0.13]
Amotivation	-.13	.005	[-0.21,-0.04]
Mental Health			
Depression	.04	.464	[-0.07,0.15]
Anxiety	.02	.738	[-0.09,0.12]
Stress	.09	.120	[-0.02,0.21]
App User (vs. non-user)	.09	.027	[0.01,0.16]

The ordinal logistic regression model accounted for 32.6% of the variance in perceived changes in physical activity behaviours during the COVID-19 lockdown (Nagelkerke R^2 of 0.326) and was significant, $\chi^2(24) = 125.7$, $P < .01$. Self-efficacy (OR = 4.2, $P < .001$) was associated with higher odds of increased physical activity during the COVID-19 lockdown after controlling for age, gender, BMI, and location (see Table 4).

Table 4

Ordinal logistic regression analysis examining the predictors of perceived change in physical activity during the COVID-19 lockdown

Variable	Estimate	*P* value	Odds ratio	OR 95% CI
Age (years) (18-30 is ref)				
>30-50	-.15	.577	0.85	[0.49,1.47]
>50	-.88	.014	0.41	[0.20,0.83]
Gender				
Female (vs. Male)	.05	.893	1.0	[0.53, 2.08]
Location (SA is ref)				
NSW	.24	.496	1.27	[0.63,2.54]
ACT	-.25	.632	0.78	[0.28,2.15]
VIC	.12	.714	1.12	[0.60,2.10]
QLD	.28	.407	1.33	[0.67,2.63]
TAS	.78	.173	2.19	[0.71,6.78]
NT	.63	.389	1.90	[0.45,7.87]
WA	.17	.689	1.19	[0.51,2.79]
BMI (kg/m^2) (normal weight 18.5-24.9 is ref)				
Underweight (<18.5)	-.28	.732	0.75	[0.15,3.75]
Overweight (25-29.9)	.48	.073	1.62	[0.95,2.75]
Obese (>30)	.38	.224	1.46	[0.79,2.72]
Psychological constructs				
Social support	.09	.669	1.09	[0.72,1.68]
Self-efficacy	1.4	<.001	4.24	[2.94,6.12]
Intrinsic motivation	.30	.052	1.35	[0.99,1.83]
Identified regulation	-.34	.093	0.71	[0.47,1.05]
Introjected regulation	.02	.827	1.02	[0.82,1.30]
External regulation	.14	.420	1.15	[0.82,1.60]
Amotivation	-.12	.534	0.88	[0.59,1.31]
Mental Health				
Depression	.01	.745	1.01	[0.95,1.07]
Anxiety	.006	.891	1.00	[0.93,1.09]
Stress	.04	.236	1.04	[0.97,1.12]
App User (vs. non-user)	.23	.349	1.25	[0.78,2.03]

Mediation Analyses; Exploring the Relationships between Commercial Physical Activity Apps, Psychological Constructs and Physical Activity

Model 1 (Physical activity (min/week)). Overall, the model accounted for a significant ($P < .001$) amount of variance in physical activity (min/week) during the COVID-19 lockdown (40.0%). There were significant, direct positive paths from app use to social support (β = 0.31 [0.23, 0.39]), self-efficacy (β = 0.27 [0.17, 0.36]), intrinsic regulation (β = 0.33 [0.24, 0.42]), and identified regulation (β = 0.32 [0.23, 0.41]). Additionally, there was a significant, direct negative path from app use to amotivation (β = -0.23 [-0.31, -0.13]). In relation to physical activity, there were significant, direct positive paths for self-efficacy (β = 0.37 [0.27, 0.47]) and identified regulation (β = 0.27 [0.12, 0.41]). The indirect effect of app use on physical activity was mediated by self-efficacy (β = 0.10 [0.06, 0.15]) and identified regulation (β = 0.09 [0.04, 0.15]), and this showed complete mediation (Direct effect: β = 0.09 [-0.005, 0.18]. This indicates that app use is associated with higher self-efficacy and identified regulation, and in turn, greater engagement in physical activity (min/week) during the COVID-19 lockdown.

Model 2 (Perceived change in physical activity). Overall, the model accounted for a significant ($P < .001$) amount of variance in perceived change in physical activity during the COVID-19 lockdown (35.0%). Significant direct paths were identified from app use to social support (OR = 1.4 [1.2, 1.5) and self-efficacy (OR = 1.3 [1.2, 1.4], intrinsic motivation (OR = 1.4 [1.3, 1.5), identified regulation (OR = 1.4 [1.3, 1.5) and amotivation (OR = 0.79 [0.73, 0.87). There was also a significant direct path from self-efficacy to perceived change in physical activity (OR = 1.7 [1.5, 1.9]). In addition, the indirect pathway from app use to perceived change in physical activity via self-efficacy was significant (β = 0.15, [0.09, 0.21]), and this showed complete mediation (Direct effect: β = 0.05 [-0.07, 0.16]. Thus, app users

were more likely to report higher self-efficacy, and in turn, were more likely to perceive positive changes (increase) in physical activity during the COVID-19 lockdown.

Discussion

This study presents a comprehensive nation-wide examination of adults' physical activity during the initial COVID-19 lockdown (April/ May 2020) in Australia. It explored the psychological (social support, self-efficacy, motivations) and mental health predictors (depression, stress, anxiety) of physical activity during the COVID-19 lockdown. It also examined the role of commercial physical activity apps in facilitating physical activity during the COVID-19 lockdown.

Participants reported engaging on average in 229 min of physical activity per week. This is lower than the average physical activity level (294 min/week) among Australian adults during non-pandemic times (Australian Bureau of Statistics, 2019). Interestingly, despite the uniform regulations about physical activity across Australia during the initial COVID-19 lockdown (e.g., closure of indoor and outdoor sporting facilities), Victorians engaged in significantly more physical activity than South Australians. This fits with reports by the Australian Bureau of Statistics (during non-pandemic times) of a slightly higher proportion of adults meeting the Physical Activity Guidelines in Victoria (15.3%) than in South Australia (14.9%) (Australian Bureau of Statistics, 2019). We also found that older adults engaged in significantly more physical activity than younger adults. This finding conflicts with extant literature pertaining to age-related patterns of physical activity decline during non-pandemic times (Bennie et al., 2015). It does, however, fit with evidence that during COVID-19, younger adults (as compared to older adults) experienced higher levels of distress (Every-Palmer et al., 2020) and loneliness (Groarke et al., 2020), and reported poorer sleep quality (Cellini et al., 2021); all factors associated with lower levels of physical activity (Gucciardi et al., 2020; Kline, 2014; Pels & Kleinert, 2016). It had also been suggested that

during COVID-19, older adults who are deemed a ‘vulnerable population’ may have developed greater concerns about health, which may have motivated them to increase their engagement in physical activity (Reynolds, 2020). Given the known links between physical activity and mental health (Mikkelsen et al., 2017), it is not surprising that the emerging COVID-19 literature (Huang & Zhao, 2020; Jia et al., 2020; Pieh, Budimir, & Probst, 2020) documents that older adults also have significantly better mental health outcomes than younger adults. This suggests that during a pandemic, physical activity interventions should be targeted at younger adults.

Most participants (77.2%) reported that their physical activity levels had changed during the initial COVID-19 lockdown. Specifically, over half of participants (53.4%) reported engaging in less physical activity than usual and markedly fewer (23.8%) reported an increase in physical activity. A study conducted by Stanton et al. (2020) on the links between changes in various health behaviours and mental health in Australian adults during COVID-19 similarly found that while almost half (48.9%) of their participants reported a reduction in physical activity since the onset of COVID-19, only 20.7% reported an increase. This is perhaps not surprising given the unique circumstances during the lockdown that may have impeded engagement in physical activity, including closure of indoor and outdoor physical activity facilities, shortages of exercise equipment to purchase, social distancing, and travel restrictions. Of particular concern is that the reported reductions in physical activity during the COVID-19 lockdown may have contributed to heightened levels of depression, anxiety, and stress compared to Australian adult population normative data (Crawford, Cayley, Lovibond, Wilson, & Hartley, 2011). Therefore, it is imperative that interventions are designed to support engagement in physical activity during a pandemic to foster positive physical and mental health outcomes.

The present study examined both psychological and mental health predictors of physical activity during the COVID-19 lockdown. We found that the psychological constructs (i.e., social support, self-efficacy and autonomous types of motivation) were positively associated with physical activity and perceived change in physical activity during the COVID-19 lockdown whereas the mental health predictors (i.e., depression, anxiety, stress) were negatively associated with physical activity during the lockdown (min/week and perceived change). This is consistent with the psychological and mental health correlates of physical activity during non-pandemic times (Anderson-Bill, Winett, & Wojcik, 2011; Mikkelsen et al., 2017; Teixeira et al., 2012; Trost et al., 2002). Interestingly, the regression analyses demonstrated that self-efficacy (an individual's beliefs pertaining to their ability to perform physical activity) was the strongest positive predictor of both physical activity and positive perceived changes (increases) in physical activity during the COVID-19 lockdown. This shows that self-efficacy is fundamental to promoting engagement in physical activity during a pandemic, and therefore, is a psychological construct that should be targeted in subsequent physical activity interventions. Social support also emerged as a positive predictor of physical activity during the COVID-19 lockdown. Existing research has demonstrated that online social networking fosters the provision of social support (Petersen et al., 2020b), and thus could be leveraged to promote physical activity during a pandemic when face-to-face support is restricted. Finally, identified regulation (personal value placed on the outcomes of physical activity) was shown to positively predict physical activity during the COVID-19 lockdown. This is not surprising given that identified regulation is an autonomous type of motivation that has consistently shown to be important in promoting physical activity behaviour during non-pandemic times (Teixeira et al., 2012), and has been shown to play a positive role in predicting physical activity intentions and habits during COVID-19 (Chirico et al., 2020; Kaushal et al., 2020). Mental health problems (anxiety, depression, stress) did

not emerge as significant predictors of physical activity or perceived change in physical activity during the COVID-19 lockdown. We did, however, find a negative correlation between mental health (depression, anxiety and stress) and the psychological constructs (e.g., self-efficacy, autonomous types of motivation) linked to physical activity during the COVID-19 lockdown, suggesting that mental health may nevertheless play an important role in physical activity engagement during a pandemic. Recent research in Australia (Stanton et al., 2020) and more broadly (Schuch et al., 2020) has identified links between mental health and physical activity during COVID-19. The present study provides an important extension to the emerging body of research (Chirico et al., 2020; Kaushal et al., 2020; Rhodes et al., 2020; Spence et al., 2021) on correlates of physical activity during COVID-19 by ascertaining the roles of the psychological constructs social support, self-efficacy and motivations along with that of mental health. Together, the findings have identified the most important predictors of physical activity during the COVID-19 lockdown, which is imperative to the development of interventions that could effectively facilitate physical activity during a pandemic.

The present study also provides novel insights into the use of commercial physical activity apps during the COVID-19 lockdown. Over half of the sample (51.2%) reported using a commercial physical activity app during this time, comparable to rates of app use (51%–53%) reported during non-pandemic times (Petersen et al., 2020a; Petersen et al., 2020b). Physical activity apps that primarily function to track or monitor behaviour were the most commonly used (e.g., Strava, Fitbit). This fits with participants reporting that they predominately engaged in running and walking during the lockdown. App users engaged in significantly more physical activity than non-users, which is consistent with extant literature during non-pandemic times (Petersen et al., 2020a; Petersen et al., 2020b). They were also more likely to report an increase in physical activity during the lockdown in comparison to non-users who largely reported a reduction in physical activity. Engagement with app-

specific communities and existing social networking platforms (in relation to physical activity) were not linked to physical activity. However, engagement with specific features of app-specific communities (receiving encouragement and engagement in competitions) and existing social networking platforms (sharing physical activity posts) were found to be valuable in facilitating physical activity, consistent with recent research conducted during non-pandemic times (Petersen et al., 2020b). Notably, physical activity app use was a significant predictor of physical activity (min/week) during the COVID-19 lockdown, highlighting its role in facilitating physical activity during a pandemic. In support, Yang and Koenigstorfer (2020) found that higher app use was associated with positive change in physical activity (pre vs during the COVID-19 lockdown), which suggests that app use may attenuate reductions in physical activity during a pandemic lockdown. Our findings also provide important insight into the capacity of physical activity apps to promote engagement in physical activity during COVID-19 by ascertaining that these apps facilitate self-efficacy and identified regulation, psychological constructs shown to be fundamental in promoting physical activity during a pandemic. Thus, it appears that commercial physical activity apps are tools that hold great potential to promote physical activity engagement during a pandemic lockdown. Future research could usefully examine app use (and physical activity) at different time points during a pandemic (post-lockdown, subsequent waves) to inform the development of app-based interventions to effectively facilitate physical activity throughout a pandemic.

Our findings have important implications for the promotion of physical activity during a pandemic. First, strategies should be implemented to facilitate engagement in physical activity during a pandemic, given that over half of participants reported a reduction in physical activity during the COVID-19 lockdown. Interventions should target young adults, all the more so as they are shown to experience greater mental health problems during the COVID-19 lockdown. Second, social support, self-efficacy and autonomous types of

motivation are psychological constructs that were fundamental in predicting physical activity during the COVID-19 lockdown, and thus should be targeted in interventions designed to promote physical activity during a pandemic. Finally, commercial physical activity apps are a promising tool to promote engagement in physical activity during a pandemic, as they were linked to higher levels of physical activity during the COVID-19 lockdown, and were shown to facilitate self-efficacy and autonomous types of motivation.

As with all studies, there are some limitations that should be acknowledged. First, the sample was predominantly female and engaged in relatively high levels of physical activity which may limit the generalisability of the results. Second, the measure of physical activity was taken retrospectively and was self-report which may have been subject to recall bias or reporting inaccuracies (e.g., over-reporting). In addition, the assessment of physical activity did not measure the intensity of the activities (i.e., light, moderate, vigorous), but instead provided insight into the type of activities (e.g., running, walking). Future research should consider using accelerometer-derived measures of physical activity in conjunction with self-report measures that have the capacity to capture both intensity and type of activities. Third, because of the synchronic measurement of physical activity and perceived change in physical activity, it is not possible to ascertain the potential role of perceptions in driving physical activity behaviour. Perceptions of past behaviour (i.e., pre-lockdown behaviour) are another important consideration in this context (e.g., Kaushal et al. 2020). Finally, the cross-sectional nature of this study precludes conclusions of causality; for example, the associations between physical activity and mental health, and the relationships between psychological constructs and commercial physical activity app use may be bi-directional.

In conclusion, the present study has provided important insights into physical activity during the COVID-19 lockdown among Australian adults. The findings indicate that strategies targeted at increasing social support, self-efficacy, and autonomous types of

motivation should be implemented to mitigate reductions and support the maintenance of physical activity during a pandemic. Commercial physical activity apps present an innovative approach to facilitating physical activity during a pandemic, and thus the use of these apps should be encouraged. Outcomes of this study have provided valuable knowledge pertaining to the promotion of physical activity during the COVID-19 lockdown that will be fundamental to facilitating positive physical and mental health outcomes in current and future pandemics.

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CHAPTER 7: GENERAL DISCUSSION

Chapter Overview

The main aim of this program of research was to provide a comprehensive understanding of the capacity of commercial physical activity apps (and their social networking functionalities) to support engagement in physical activity. This was achieved by a systematic literature review, and four studies using cross-sectional and longitudinal research designs. This general discussion chapter will first provide a summary of the key findings. Next, the theoretical and practical implications will be discussed. Finally, strengths and limitations of the program of research, and considerations for future research will be discussed.

Summary of Findings

The overarching aim of this program of research was addressed by a series of studies. Study 1 (Chapter 2), a systematic review, evaluated the existing literature on physical activity apps (commercial and research apps), and the additive value of existing social networking platforms (e.g., Facebook, Instagram). The findings indicated that physical activity apps (largely developed for research purposes) demonstrated the capacity to increase physical activity in diverse populations. Additionally, existing social networking platforms showed the potential to enhance the engagement with, and thus, the effectiveness of physical activity apps. The review concluded that further research was necessary to examine commercial physical activity apps and the social networking functionalities common to such apps (e.g., existing social networking platforms).

Study 2, presented in Chapter 3, therefore, examined the capacity of commercial physical activity apps to promote physical activity engagement. This study also explored the value of the social networking functionalities of these apps (app communities, existing social

networking platforms) in supporting physical activity. The findings indicated that commercial physical activity app use was associated with higher engagement in physical activity, as was the use of app communities and existing social networking platforms (e.g., Facebook). Study 3 (Chapter 4) aimed to extend these findings by examining the psychological mechanisms underlying the relationship between the use of commercial physical activity apps (and their social networking functionalities) and physical activity engagement. The role of individual difference characteristics (i.e., trait competitiveness and trait social comparisons) was also explored. The findings showed that the relationship between app use and physical activity was mediated by social support, self-efficacy, and autonomous types of motivation (intrinsic and identified). There were also mediation pathways linking features of existing social networking platforms with physical activity. Specifically, sharing physical activity posts to these platforms was linked to higher engagement in physical activity via positive associations with self-efficacy, and receiving encouragement was linked to higher engagement in physical activity via positive associations with both self-efficacy and identified regulation. Engagement in comparisons was, however, associated with lower self-efficacy and higher external regulation, and in turn, lower levels of physical activity. In addition, trait competitiveness, but not trait social comparison, moderated the relationship between app use and physical activity, such that app users with higher trait competitiveness engaged in more physical activity.

Study 4 (Chapter 5) examined the longitudinal associations between the use of commercial physical activity apps (and their social networking functionalities) and engagement in physical activity over a 6-month period. The roles of social support, self-efficacy, and motivation in the longitudinal associations between commercial app use and physical activity were also investigated. The findings showed that commercial physical activity app use was associated with significantly higher levels of physical activity over the 6-

month period. Among app users, sharing physical activity behaviour to existing social networking platforms also positively predicted longer-term physical activity engagement. However, after adjusting for psychological constructs (social support, self-efficacy, and motivation), physical activity app use (and sharing physical activity to existing social networking platforms) were no longer significant predictors of physical activity engagement. Instead, social support, self-efficacy, identified regulation and introjected regulation emerged as positive predictors of physical activity over the 6-month period.

Finally, in Study 5 (Chapter 6), the timing of the program of research provided the unique opportunity to explore the value of commercial physical activity apps in supporting engagement in physical activity during a pandemic. This study also examined the psychological (social support, self-efficacy, motivations) and mental health predictors (depression, stress, anxiety) of physical activity during the 2020 COVID-19 lockdown in Australia. Commercial physical activity app use emerged as an important predictor of physical activity engagement during lockdown, along with social support, self-efficacy and identified regulation. The findings further showed that the relationship between app use and physical activity was mediated by self-efficacy and identified regulation. Self-efficacy also mediated the relationship between app use and positive perceived change (increase) in physical activity.

Theoretical Implications

The present program of research has important theoretical implications. First, in Study 1 (Chapter 2), the systematic literature review identified that most apps (commercial and research apps) were underpinned by theoretical frameworks (e.g., Social Cognitive Theory, Self-determination Theory). Few studies had, however, evaluated the apps in relation to the constructs embedded within the frameworks, known as the antecedents of behaviour change

(Michie & Prestwich, 2010). Study 3 (Chapter 4), therefore, sought to determine the capacity of commercial apps to support physical activity engagement, by ascertaining their associations with social support, self-efficacy, and motivation, constructs common to many theoretical frameworks. The findings indicated that commercial physical activity app use was associated with greater social support, self-efficacy, and autonomous types of motivation (intrinsic motivation, identified regulation), and in turn, greater engagement in physical activity. These findings extend existing research that has demonstrated the important role of social support and self-efficacy in the relationship between app use and physical activity (Litman et al., 2015; Wang et al., 2019). In Study 4 (Chapter 5), commercial physical activity app use predicted greater physical activity over a 6-month period, although after controlling for psychological constructs (social support, self-efficacy, motivation) this relationship was no longer significant. Instead, social support, self-efficacy and identified regulation emerged as the strongest predictors of physical activity over time, further suggesting that these constructs may play an important underlying role in the relationship between commercial physical activity app use and long-term physical activity. Finally, Study 5 (Chapter 6) was the first to identify that self-efficacy and autonomous types of motivation (identified regulation) also underpinned the positive relationship between app use and physical activity during a pandemic.

Study 3 (Chapter 4) examined the mechanisms underlying the associations between the use of the social networking functionalities of commercial physical activity apps and physical activity behaviour. Sharing physical activity behaviour to existing social networking platforms (generating positive encouragement) was positively associated with self-efficacy and autonomous types of motivation (identified regulation). Oeldorf-Hirsch, High and Christensen (2019) similarly reported that sharing tracked health information to social networking platforms (e.g., physical activity, sleep, calories) was linked to increased health

behaviour by fostering the provision of support, a recognised precursor to self-efficacy (Bandura, 1999; Rovniak, Anderson, Winett, & Stephens, 2002).

Together, these findings lend additional support to the importance of social support and self-efficacy in physical activity promotion, along with autonomous (rather than controlled) types of motivation, consistent with existing evidence pertaining to motivation in the context of Self-determination Theory (Teixeira, Carraça, Markland, Silva, & Ryan, 2012). The findings also suggest that commercial physical activity apps (and their social networking functionalities) have potential to be of great benefit in improving physical activity engagement, given their associations with self-efficacy, social support, and autonomous types of motivation that are among the most consistent and reliable predictors of physical activity (Bauman et al., 2012; Choi, Lee, Lee, Kang, & Choi, 2017; Rhodes, Janssen, Bredin, Warburton, & Bauman, 2017; Trost, Owen, Bauman, Sallis, & Brown, 2002). These associations may be attributed to the behaviour change techniques often incorporated in commercial physical activity apps that are shown to promote increased self-efficacy, social support and autonomous types of motivation (Bondaronek et al., 2018). More specifically, these apps incorporate behaviour change techniques including self-monitoring, reinforcements, and provision of instructions that are linked to enhanced self-efficacy (Olander et al., 2013; Williams & French, 2011), along with goal-setting, provision of feedback on performance, and demonstration of behaviour that are associated with increased autonomous types of motivation (Knittle et al., 2018; Teixeira et al., 2020). It should, however, be acknowledged that the cross-sectional nature of this research precludes conclusions of causality; it is possible that those with higher social support, self-efficacy or motivation were more active, and attracted to apps to monitor (and share) their physical activity behaviour. Experimental research could usefully ascertain whether commercial physical activity apps have the potential to support positive changes in constructs linked to

physical activity, for example, by effecting a shift in one's motivational profile (e.g., a shift from controlled motivations towards autonomous types of motivation).

This program of research indicates that social support, self-efficacy, and autonomous types of motivation may play an important underlying role in the relationship between commercial physical activity app use and physical activity engagement. This speaks to the behaviour change potential of these apps given that social support, self-efficacy and motivation are core to many theoretical frameworks, and are central tenants of the Capability Opportunity Motivation Behaviour (COM-B) framework (Michie, Van Stralen, & West, 2011). More specifically, the COM-B situated at the centre of the Behaviour Change Wheel (synthesised from 19 theoretical frameworks), posits that capability (physical and psychological), opportunity (social and physical influences) and motivation interact to drive behaviour (e.g., physical activity) (Michie et al., 2011). In the present research, the mechanisms underlying the positive relationship between commercial app use and physical activity lend further support to the core components of the COM-B. This framework could, therefore, be valuable in guiding the development of effective app-based interventions. More specifically, the Behaviour Change Wheel provides intervention strategies (e.g., education, persuasion, incentivisation, modelling) targeted at facilitating capability, opportunity, and motivation, that could be beneficial to consider in the development of such interventions. It has, however, been recognised that there is also a need to consider theoretical frameworks that provide guidance in relation to enhancing engagement with an app-based intervention (Vandelanotte et al., 2016). For example, the Model of User Engagement proposes that factors related to the: (1) environment (e.g., time, internet access), (2) individual (e.g., demographics), and (3) intervention design (e.g., usability, aesthetics), interact to influence the engagement with, and persuasiveness of an online intervention (Short et al., 2015). Harnessing such models, in addition to traditional behaviour change theories (e.g., Behaviour

Change Wheel) will be beneficial in guiding the design of app-based interventions that target both the determinants of behaviour change and user engagement.

Practical Implications

Physical Activity Promotion

This program of research has implications for the promotion of physical activity. The World Health Organisation's Global Action Plan on Physical Activity 2018-2030 recommends the evaluation of innovative digital technologies to accelerate the development and implementation of effective solutions targeted at increasing physical activity (World Health Organization, 2019). This underscores the importance of the present research in providing a comprehensive insight into the value of commercial physical activity apps in supporting an active lifestyle. First, the findings presented in Study 2 (Chapter 3) indicate that commercial physical activity apps are an accessible and appealing tool to support health behaviour, and are accepted by the population at large, and thus, may have immense public health impact. Study 2 (Chapter 3) further found that those using commercial physical activity apps engaged in 30% more physical activity per week (90 min/ week) than non-users, suggesting that these apps are beneficial in promoting engagement in physical activity. This supports and extends two existing studies documenting that commercial physical activity app use is associated with higher engagement in physical activity (Litman et al., 2015; Wang et al., 2019). It must be acknowledged that the cross-sectional nature of the present research limits conclusions of causality; it is possible that those attracted to apps are more physically active. Nevertheless, Study 4 (Chapter 5) was one of the first to examine the longitudinal associations between commercial physical activity app use and physical activity engagement, thereby providing some evidence for potential temporal relations among these variables. The findings showed that commercial physical activity app use predicted greater physical activity

over a 6-month period, with app users engaging in an average of 59 minutes more physical activity per week than non-users. This suggests that these apps are valuable in supporting longer-term engagement in physical activity, important to optimising health outcomes (Rhodes et al., 2017; Warburton, Nicol, & Bredin, 2006). Finally, Study 5 (Chapter 6) found that commercial physical activity apps also have the potential to support engagement in physical activity during a pandemic lockdown, as also found by Yang and Koenigstorfer (2020). Taken together, the present set of studies indicate that commercial physical activity apps hold great potential to promote and maintain physical activity engagement.

The current program of research also provided a novel insight into the value of social networking functionalities of commercial physical activity apps (app communities, existing social networking platforms) in supporting physical activity engagement. Specifically, Study 2 (Chapter 3) found that the use of these social networking functionalities of commercial physical activity apps were associated with higher physical activity engagement, suggesting they have the potential to be of benefit in promoting an active lifestyle. This is consistent with recent evidence indicating that interacting with other app users (i.e., receiving "likes" and "comments") supports physical activity engagement (Yin, Li, Yan, & Guo, 2021). It also provides an important extension to existing research suggesting that these app communities have the capacity to enhance users' experience (e.g., enjoyment) and facilitate habitual app use (Stragier, Abeele, Mechant, & De Marez, 2016). However, Study 2 (Chapter 3) indicated that few users engaged with app communities (relative to existing social networking communities), and this may limit their utility to support physical activity.

Several studies in the present program of research suggested that existing social networking platforms may be particularly valuable to maximising the effectiveness of physical activity apps. In Study 1 (Chapter 2), the systematic literature review concluded that existing social networking platforms are beneficial in increasing engagement with physical

activity apps, important given that higher engagement plays a well-substantiated role in the effectiveness of these apps (Romeo et al., 2019; Schoeppe et al., 2016). The subsequent studies provided further evidence to indicate that the use of existing social networking platforms, specifically sharing physical activity behaviour, supports physical activity engagement. In Study 2 (Chapter 3), sharing physical activity to existing social networking platforms was identified as a key predictor of physical activity engagement, and in Study 4 (Chapter 5) it was shown to predict longer-term engagement in physical activity. Study 5 (Chapter 6) similarly indicated that sharing physical activity to existing social networking platforms was linked to being more active during COVID-19. Extant research has suggested that existing social networking platforms, which are inherently popular and well-integrated into daily life, could be key to improving the effectiveness of health interventions (e.g., apps) (Laranjo et al., 2015; Maher et al., 2014). The present program of research indicated that these platforms are indeed beneficial in supporting physical activity engagement. There are, however, some risks associated with social networking platforms that should be considered when harnessing such platforms for health promotion efforts including limited control over settings and features, regular changes to functionality, and privacy violations (Arigo et al., 2018).

Physical Activity Promotion: Inactive Subpopulations

This program of research has important implications for the promotion of physical activity in the general population and in sub-populations that are highly inactive. For example, many individuals with chronic disease (e.g., heart disease, diabetes) do not meet the physical activity guidelines, despite physical activity being a key component in the prevention or self-management of these conditions. Existing research examining the use of smartphone apps for such individuals has focused on apps that simultaneously target a range of self-management behaviours (e.g., DiabetesConnect app; medication management, glucose

monitoring, nutrition) (Jimenez, Lum, & Car, 2019; Martínez-Pérez, de la Torre-Díez, & López-Coronado, 2013). However, few of these apps incorporate features targeted at promoting physical activity or the functionality to facilitate social connections (Hood et al., 2016). This program of research indicates that commercial physical activity apps may provide a promising approach to improve physical activity in populations with a range of chronic diseases. The applicability of the current findings to such populations will subsequently be demonstrated in relation to diabetes (see Appendix G), the most prevalent chronic disease in Australian adults (Australian Government Department of Health, 2020). First, several studies (Studies 1-5; Chapters 2-6) showed that commercial physical activity apps were beneficial in supporting physical activity, and notably, prolonged engagement in physical activity (Study 4; Chapter 5), important in the long-term management of diabetes. Second, Study 3 (Chapter 4) further showed that commercial physical activity apps have the capacity to foster social support, and positively influence motivation and self-efficacy. These apps may, therefore, be particularly valuable for inactive individuals with diabetes given that lack of social support, self-efficacy, and motivation are documented as key barriers to physical activity in this population (Brennan, Brown, Ntoumanis, & Leslie, 2021; Ghimire, 2017; Lidegaard, Schwennesen, Willaing, & Færch, 2016). Finally, the social networking functionalities of these apps may be critical to improving physical activity among persons with diabetes, given their capacity to support physical activity engagement (Studies 1-5; Chapters 2-6) coupled with evidence suggesting they are valued by this population (Adu, Malabu, Malau-Aduli, & Malau-Aduli, 2018). These functionalities are also beneficial in their potential to foster support from others who may share similar experiences in relation to physical activity, as well as those without diabetes who share a common behavioural goal (e.g., physical activity engagement). Further research investigating commercially available physical activity apps for inactive individuals and those with chronic conditions is warranted.

From a public health perspective, the present program of research indicates that commercial physical activity apps provide unparalleled opportunities to increase population-level physical activity, and thus achieve WHO physical inactivity reduction targets (World Health Organization, 2019).

Development of Future Apps

This program of research has important implications for the development of physical activity apps in the future, in particular regarding the enhancement of existing features. Specifically, the research has shown that the social networking functionalities of commercial physical activity apps are valuable in supporting physical activity engagement (Studies 1-5, Chapters 2-6). These apps should therefore, incorporate features that promote their use. For example, reminders, push notifications or chatbots could be harnessed to inform users of the evidence-based benefits of engaging with these functionalities to support their use. This is necessary given that Study 2 (Chapter 3) showed that less than half of all app users engaged with the community, along with existing evidence suggesting that some users are reluctant to share their tracked physical activity as they do not see the merit of doing so (Baretta, Perski, & Steca, 2019).

Physical activity apps also have adaptive capabilities to tailor the user experience to personal characteristics, and this functionality has been shown to be valued by app users (Baretta et al., 2019; D'Addario, Baretta, Zanatta, Greco, & Steca, 2020; Vaghefi & Tulu, 2019). In line with the findings documented in Study 3 (Chapter 4) and Study 5 (Chapter 6), this functionality could usefully be leveraged to tailor app content according to user characteristics (i.e., social support, self-efficacy, and motivation) to maximise the effectiveness of such apps in supporting physical activity engagement. For example, this could be implemented by adapting the provision of features previously shown to support

increased physical activity self-efficacy (e.g., reinforcements, providing instructions, action planning) (Williams & French, 2011). Relatedly, in Study 3 (Chapter 4), those with competitive tendencies were found to benefit most from commercial physical activity apps, suggesting that users' individual differences should be considered in the design of such apps. This fits with extant evidence indicating that a one-size-fits all approach is not appropriate when harnessing functionalities such as those that facilitate competitions or comparisons (Arigo, Brown, Pasko, & Suls, 2020; Tong & Laranjo, 2018). These functionalities (e.g., leader boards, daily/weekly challenges) may instead, be of most value when tailored to user characteristics and/or preferences.

Limitations and Future Directions

The current program of research has several strengths. First, the research used a breadth of study designs (systematic review, cross-sectional and longitudinal designs) to provide a comprehensive and novel insight into the value of commercial physical activity apps (and their social networking functionality) to support physical activity engagement. Second, all studies incorporated a relatively large sample size (>700 participants), and participants were recruited from a range of settings including a university campus, online social networking platforms, and the wider community. Finally, this program of research has evaluated digital technologies (commercial apps, online social networking) that are highly accessible, convenient, inexpensive and afford widespread reach. This research is also particularly timely in the context of the current COVID-19 pandemic. It is, therefore, clear that this body of research has the potential for immense public health impact.

It is also important to acknowledge the limitations of this program of research, and in doing so, highlight potential avenues for future research. First, this body of research utilised self-report measures of physical activity and app use which may be subject to reporting inaccuracies. The assessment of physical activity following the methods of Prichard and

Tiggemann (2008), did, however, provide insight into the type of activities (e.g., running, walking) participants were engaging in, important given this is often captured by apps that track or monitor physical activity. Future research should consider supplementing self-report measures of physical activity and app use with objective assessments (e.g., accelerometer-derived, Google Analytics, respectively).

Second, the research recruited individuals who were existing users of commercial physical activity apps and already engaging in higher-than-average levels of physical activity. Thus, the findings may not be generalisable to inactive individuals. For example, it is possible that those seeking assistance from apps to support the initiation of physical activity behaviour may have different preferences pertaining to design and function of such apps to those who are existing users and seeking to maintain or improve behaviour. Future research should, therefore, determine how best to leverage commercial apps to support individuals to initiate and maintain physical activity engagement.

Third, while this body of work has significantly progressed an important field of research, its largely correlational nature precludes conclusions of causality. A logical next step is to experimentally examine commercial physical activity apps (and their social networking functionalities), especially given the dearth of research that has rigorously evaluated these digital technologies (Study 1; Chapter 2). In particular, randomised controlled trials should be conducted to evaluate the effectiveness and feasibility (cost effectiveness, usability, acceptability) of commercial physical activity apps. As outlined in the General Introduction (Chapter 1), a randomised controlled trial informed by the findings of this program of research had been developed, and involved evaluating the effectiveness of a widely used commercial physical activity app (Strava) and its social networking functionalities. The field would benefit from conducting such a trial in future. Additionally,

ecologically valid trials are necessary to examine the engagement with, and effectiveness of, physical activity apps in real-world circumstances (Vandelanotte et al., 2019).

Fourth, wearable activity trackers, devices that allow the automated self-monitoring of behaviour and often used in tandem with physical activity apps, were not specifically examined in this body of work. The popularity of these devices has rapidly increased since the conception of this program of research, as too the evidence pertaining to their effectiveness (Li, Chen, & Bi, 2021). Wearable activity trackers are, however, often costly and evidence has cited limitations to their usability (Maher et al., 2017). Commercial physical activity apps were the key focus of this body of work, given the death of research in relation to such apps, despite their accessibility and affordability. Many physical activity apps also allow the tracking of behaviour (inbuilt accelerometry), in addition to functionality beyond that of wearable tracking devices such as social networking functionalities shown to support physical activity engagement (Studies 1-5; Chapters 2-6). Future research should endeavour to determine the comparative effectiveness of engaging with commercial physical activity apps and/ or wearable activity devices.

Finally, the current program of research focused on the use of physical activity apps to support engagement in healthy behaviours. It is, however, important to acknowledge that there are possible adverse consequences of engaging with this technology. For example, functionalities, such as those that facilitate food logging or calorie tracking, common to many health and fitness apps, are suggested to foster maladaptive eating and exercise behaviours (e.g., restrictive eating, excessive exercising) (Honary, Bell, Clinch, Wild, & McNaney, 2019). In the present research, however, Garmin, Strava and Fitbit, apps that primarily function to track physical activity behaviour, were most commonly used. Further, apps incorporating features such as weight monitoring that foster appearance, rather than functional-related goals for physical activity, may adversely influence users' body image,

mental health, eating and exercise behaviours (DiBartolo, Lin, Montoya, Neal, & Shaffer, 2007; Panão & Carraça, 2020; Prichard & Tiggemann, 2008). Future research could usefully conduct a systematic audit of commercially available apps to assess their quality and behaviour change potential, in addition to their focus on appearance or functional-related reasons for physical activity. Moreover, while the current program of research has largely shown that the social networking functionalities of commercial physical activity apps are valuable in supporting physical activity, it was found that engaging in comparisons on existing social networking platforms may be demotivating (Study 3; Chapter 4). Extant research has provided mixed evidence as to whether online comparisons are harmful or beneficial in supporting health behaviour (Arigo, Pasko, & Mogle, 2020; Luszczynska, Gibbons, Piko, & Tekozel, 2004). Future research should, therefore, determine how online comparisons can be leveraged to support health behaviour, for example, the type and content of social networking posts that are most valuable.

Recommendations

Recommendations for consumers, health professionals and researchers are proposed based on this program of research:

Consumers

1. Physical activity apps can support your engagement in physical activity, and thus optimise your health outcomes
2. Apps that primarily function to track or monitor physical activity behaviour (e.g., Fitbit, Strava, Garmin) will be of most benefit
3. Engagement with the social networking functionalities of physical activity apps, in particular sharing physical activity to social networking platforms (e.g., Facebook) can support your physical activity engagement

4. Consider the specific type(s) of physical activity (e.g., aerobic exercise, resistance exercise) targeted by an app to ensure the selected app(s) will support you to achieve the physical activity guidelines
5. Apps should be customisable in accordance with personal preferences and needs
6. Physical activity apps that incorporate guided workouts or training programs should be evidence-based

Health Professionals

1. Commercial physical activity apps have the capacity to promote engagement in physical activity in the population broadly, and thus their use should be recommended
2. The use of the social networking functionalities of physical activity apps should be encouraged to promote increased engagement in physical activity. For example, sharing tracked physical activity to social networking platforms (e.g., Facebook) will support physical activity
3. Physical activity apps incorporating features and functionality (e.g., self-monitoring, reinforcements, goal setting) that target important determinants of physical activity engagement (e.g., self-efficacy, social support, autonomous types of motivation) should be recommended
4. Physical activity apps that incorporate guided workouts or training programs should be evidence-based or developed in consultation with a reputable source (e.g., health professional/s)
5. The specific type(s) of physical activity (e.g., aerobic exercise, resistance exercise) that are targeted by an app should be considered to ensure the selected app(s) will support individuals to meet the physical activity guidelines

6. Apps should incorporate content and functionality that is tailored to an individual's preferences and needs, rather than a one-size fits all approach. The suitability of an app may differ according to one's preferences, age, or gender

Researchers

1. Conduct randomised controlled trials to further progress the field, in addition to ecologically valid or pragmatic trials to assess the engagement with, and effectiveness of apps, in real-world conditions
2. Evaluate the capacity of commercial physical activity apps to initiate and maintain physical activity in inactive and clinical populations
3. Evaluate the effectiveness of different types of apps (e.g., apps that track/ monitor behaviour *vs* those that provide guided workouts or training programs)
4. Examine the importance of alternative features of commercial physical activity apps (e.g., goal-setting, reinforcements) in supporting physical activity
5. Systematically audit the quality and behaviour change potential of commercial physical activity apps to provide valuable guidance to health professionals and consumers
6. Utilise theoretical frameworks (e.g., Behaviour Change Wheel) that target important determinants of physical activity engagement (e.g., self-efficacy, social support, autonomous types of motivation) to inform the development of app-based interventions

Conclusion

The present program of research addressed the overarching aim of providing a comprehensive understanding of the capacity of commercial physical activity apps (and their social networking functionalities) to support engagement in physical activity. This research has shown that commercial physical activity apps (and their social networking

functionalities) hold great potential to promote physical activity engagement. The outcomes from this body of work have significantly progressed an important field of research and are fundamental to facilitating widespread improvements in physical activity engagement to optimise population physical and mental health outcomes. Future experimental research should evaluate the effectiveness of commercial physical activity apps in supporting the initiation and maintenance of physical activity engagement in inactive populations.

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APPENDIX A

Summary of App Alone Studies

Reference	Country	Sample Characteristics	Study Design	Description of Intervention	Physical Activity Outcome Measure(s)	Other Measures	Key Findings	Behaviour Change Theory	Study Quality
Arrogi et al. (2019)	United Kingdom	58 participants (51 analysed) 18-55 years Mean age: 36.2 years (10.2) 41.10% females Sedentary lifestyle	2-week, 2-group RCT Pre-intervention assessments: 1-week	*Mobile application* stApp (newly developed): Alarm alert after 25 and 30 minutes of prolonged sitting; tailored feedback based on sitting behaviour; information to reduce sitting behaviour; encouragement; motion sensor to detect sitting behaviour *Intervention condition* (*n* = 28) Received stApp; wore activPAL3 inclinometer *Control condition* (*n* = 23) Did not receive stApp; wore activPAL3 inclinometer	*Pre-intervention & 2 weeks* activPAL3 inclinometer Sitting behaviour		*Physical activity outcomes* Significant group by time interaction for total sitting time on week days, *P* = .03, *d* = 0.62. Total sitting time significantly decreased in the intervention condition from baseline (*M* = 633.9, *SD* = 81.9) to post-intervention (*M* = 593.4, *SD* = 111.5) (*P* = .002, *d* = 0.41). No significant difference in control condition from baseline (*M* = 658.4, *SD* = 74.4) to post-intervention (*M* = 658.1, *SD* = 66.0) (*P* > .05, *d* = 0.00). Significant group by time interaction for prolonged sitting bouts on week days (*P* < .001, *d* = 1.35). Significant decrease in prolonged sitting bouts on week days in the intervention condition from baseline (*M* = 6.2, *SD* = 1.6) to post-intervention (*M* =3.4, *SD* = 2.0) (*P* < .001, *d* = 1.5). No significant difference in prolonged sitting bouts on week days in control condition from baseline (*M* = 6.7, *SD* = 1.8) to post-intervention (*M* =	Social Cognitive Theory; Control Theory	57%; fair

							6.3, *SD* = 1.9 (*P* > .05, *d* = 0.22).		
Bond et al. (2014)	USA	30 participants 21-70 years Mean age: 47.5 years (13.5) 83.3% female Overweight or obese (BMI = ≥ 25 kg/m^2)	28-days within-subject, pre-post design Pre-intervention assessments: 1-week	*Mobile application* B-MOBILE Application (newly developed): Audible prompts and reminders based on break goal condition (see below); accelerometer to monitor sedentary behaviour; tracking of total sedentary and active minutes accumulated throughout the day; praise for compliance with physical activity break prompts 3 physical activity break goal conditions: 1. 3 minute break after 30 continuous minutes of sedentary behaviour 2. 6 minute break after 60 continuous minutes of sedentary behaviour 3. 12 minute break after 120 continuous minutes of sedentary behaviour *Intervention* 10 minutes of in-person education at the start of the intervention on reducing sedentary behaviour; received B-MOBILE application; engagement in each of the 3 conditions for a 7-day period; wore SenseWear Mini Armband monitor	*Pre-intervention & during all 3 conditions* SenseWear Mini Armband monitor Objective measure of sedentary behaviour, light and moderate-to-vigorous intensity physical activity (MVPA)		*Physical activity outcomes (M & SD not reported)* Percentage of time spent in sedentary behaviour was significantly decreased in all 3 conditions relative to baseline (*P* < .005). Percent time spent in light (*P* < .05) and MVPA (*P* < .01) significantly increased in all 3 conditions relative to baseline.	Not Reported	75%; good
Choi et al. (2016)	USA	30 participants 18-40 years Mean age 33.7 years (2.6)	12-week, 2-group RCT Pre-intervention assessments: 1-2 weeks	*Mobile application* Fitbit (commercially available): Self-monitoring; displays steps, distance, flights of steps climbed and calories expended; automated daily messages to support physical	*Pre-intervention & 12 weeks* Fitbit Ultra Weekly step counts	*Pre-intervention & 12 weeks* Self-efficacy for Physical Activity Social Support and Exercise Survey	*Physical activity outcomes* No significant between-group change in mean daily steps, *P* = .23.	Social Cognitive Theory	88%; good

		100% female Pregnant (10-40 weeks gestation) & sedentary lifestyle		activity; activity diary to report daily steps, type and duration of physical activity engaged in; feedback given on progress; tips for physical activity, healthy diet and weight management during pregnancy *Intervention condition (n = 15)* Received mobile application; initial in-person session: provision of information including; physical activity recommendations for pregnant women; goal setting; and safety instructions for increasing physical activity during pregnancy; wore a Fitbit Ultra *Control condition (n = 15)* Did not received mobile application; initial in-person session: recommendations for increasing physical activity during pregnancy and safety instructions for increasing physical activity during pregnancy; wore a Fitbit Ultra		App engagement Responses to automated daily messages and logging of physical activity in application activity diary	*Psychosocial outcomes* Significant between-group change in lack of energy as barrier to exercising, $P = .02$. Intervention condition; baseline ($M = 5.13$, $SD = 2.56$); post intervention ($M = 3.62$, $SD = 2.90$). Control condition; baseline ($M = 4.13$, $SD = 2.59$); post- intervention ($M = 4.80$, $SD = 2.08$). No significant between-group changes in self-efficacy ($P = .58$) or social support from family ($P = .28$) and friends ($P = .64$). *Intervention engagement* Decrease in responding to daily messages and logging of physical activity in activity diary (P-value not reported). Insufficient data to calculate effect sizes		
Cowdery et al. (2015)	USA	40 participants 18-69 years Median age: 32 years 85% female	12-week, 2-group RCT Pre-intervention assessments: Initial in-person session	*Mobile application* Zombies, Run! (Commercially available): Immersive running game; audio adventure; player collects supplies and avoids being attacked by Zombies as they exercise The Walk (Commercially available): Audio adventure game; episodes and challenges; tasked with a package that must be delivered in order to save the world	*Pre-intervention & 12 weeks* International Physical Activity Questionnaire (IPAQ)-Short Form Weekly minutes of light, moderate and vigorous physical activity	*Pre-intervention & 12 weeks* Physical Activity Enjoyment Scale Treatment Self-Regulation Questionnaire for exercise; Autonomous motivation, controlled motivation and amotivation Perceived Competence for	*Physical activity outcomes* No significant group by time interaction for light ($P = .32$) moderate ($P = .57$) or vigorous physical activity ($P = .87$). *Psychosocial outcomes* No significant group by time interaction for physical activity enjoyment ($P = .66$) autonomous motivation ($P = .92$), controlled motivation ($P = .69$), amotivation ($P = .16$) or perceived competence ($P = .06$).	Self-determination Theory	59%; fair

				Intervention condition (*n* = 20) Choice between one of the two applications; tracking app (MOVES); weekly motivational emails *Control condition (n = 20)* Did not receive a commercially available app; tracking app (MOVES)		Exercising Regularly Scale	Insufficient data to calculate effect sizes		
Fanning et al. (2017)	USA	116 participants (96 analysed) 30-54 years Mean age: 41.38 years (7.57) 80% female Low-active	12-week, 4-group randomised factorial trial Pre-intervention assessments: 1-week	*Mobile application* Base application (newly developed): Tracking; instant feedback; bi-weekly feedback Four versions of the base application with additional features: 1. Goal setting & points 2. Goal setting 3. Points 4. Base app only *Intervention* Initial in-person session on goal setting; provided with one of the four versions of the application; wore Actigraph accelerometer	*Pre-intervention & 12 weeks* Actigraph accelerometer (worn on 7 consecutive days) Average daily minutes of MVPA	*Pre-intervention & 12 weeks* The exercise self-efficacy scale Barriers specific self-efficacy scale Perceived barriers to exercise Outcome expectations for exercise App engagement Recorded by app (date and time app was opened)	*Physical activity outcomes* Significant increase in MVPA across the intervention from baseline (M = 34.88, SD = 1.62) to 12 weeks (M = 46.77, SD = 1.65) (P < .01, d = 0.70). *Psychosocial outcomes* Significant decrease in perceived barriers to exercising across the intervention from baseline (M = 62.38, SD = 0.87) to 12 weeks (M = 54.54, SD = 1.10) (P = .01, d = 0.73). No significant changes in exercise self-efficacy; (P = .12, d = -0.24), barriers specific self-efficacy; (P = .11, d = -0.14), and outcome expectations (P = .34, d = 0.04). *Intervention engagement* App use significantly decreased across the intervention period (P < .01).	Social Cognitive Theory	76%; good
Glynn et al. (2014)	Ireland	90 participants (77 analysed) Mean age: 44.1years (11.5)	8-week, 2 group RCT Pre-intervention assessments: 1-week	*Mobile Application* Accupedo-Pro Pedometer App (commercially available): Tracking of daily step count and calories burnt; automatic	*Pre-intervention & 8 weeks* Accupodo-Pro Pedometer App Daily step count		*Physical activity outcomes* Significant between-group difference in daily step count, P = .02. Intervention condition; baseline (M = 4365,	Not reported	82%; good

		64% female Primary care		feedback; step history; and goal achievement *Intervention condition (n = 45)* Provision of the application on phone; instructions on how to use application; given physical activity goal (10, 000 steps per day); information on benefits of exercise *Control condition (n = 45)* Provision of the application on phone; application not made visible on phone and no instructions on how to use app; given physical activity goal (walking for 30 minutes per day); information on benefits of exercise			*SD* = 3873); post-intervention (*M* = 5855, *SD* = 4264) (*d* = 0.37). Control condition; baseline (*M* = 5138, *SD* = 3873); post-intervention (*M* = 4859, *SD* = 3474) (*d* = 0.07).		
Korinek et al. (2018)	USA	20 participants 40-65 years Mean age: 47.25 years (6.16) 90% female Overweight (BMI of 25-45 kg/m^2) & insufficiently active	14-week within-subject, pre-post design Pre-intervention assessments: 2 weeks	*Mobile Application* Just Walk Application (newly developed): Adaptive step goals; points received for achieving daily steps goals; monitoring of progress *Intervention* Received Just Walk Application; wore Fitbit Zip	*Pre-intervention & 14 weeks* Fitbit Zip Daily step count		*Physical activity outcomes* (*M* & *SD* not reported) A significant increase in daily steps (*P* < .01). Insufficient data to calculate effect sizes	Social Cognitive Theory	68%; good
Pellegrini et al. (2015)	USA	9 participants (8 analysed) 21-70 years Mean age: 53.1 years (10.7) 77% female	1-month within-subject, pre-post design Pre-intervention assessments: 10-12 days	*Mobile Application* NEAT! application (newly developed): Prompts (noise or vibration) to stand after 20 minutes of consecutive sedentary time *Intervention*	*Pre-intervention & 1-month* Actigraph Accelerometer (worn on 10 consecutive days) Sedentary behaviour, light physical activity, and MVPA	*Over 1-month intervention period* App engagement Days and hours of usage	*Physical activity outcomes* (*M* & *SD* not reported for *n* = 8) No significant decrease in sedentary time (*P* = .08). Significant increase in light physical activity (*P* = .04). No significant changes in MVPA (*P*-value not reported).	Not reported	53%; fair

		Type 2 diabetes & sedentary lifestyle		Received NEAT! Application; wore Actigraph accelerometer			*Intervention engagement* Used app on 21.9 (8.0) days for 7.6 (2.5) hours. Insufficient data to calculate effect sizes		
Simons et al. (2018)	United Kingdom	130 participants 18-30 years Mean age: 25 years (3.0) 51.5% female Low-active	9-week, 2 group RCT Pre-intervention assessments: 1-week Follow-up assessments: 3 months post-intervention	*Mobile Application* Active Coach app (newly developed): 9-week program; tailored personal goals; feedback on goal achievement; tips and facts provided through notifications to encourage physical activity; self-monitoring of steps *Intervention condition (n = 60)* Received Active Coach app; wore Fitbit Charge. *Control condition (n = 70)* Did not receive app; brochure with information and tips to encourage physical activity.	*Pre & post-intervention & follow-up* Actigraph accelerometer (worn on 7 consecutive days); light, moderate and vigorous physical activity, MVPA, and steps International Physical Activity Questionnaire (IPAQ); Frequency and duration of occupational physical activity, active transport, household physical activity and recreational physical activity	*Pre & post-intervention & follow-up* Face-to-face interview Psychosocial variables; social support, attitude (perceived benefits and barriers) and self-efficacy App engagement Google Analytics to obtain number and duration of app visits, and monitoring of frequency of reading messages relating to goals, tips and facts	*Physical activity outcomes* No significant group by time interaction for objective measures of physical activity including, light physical activity (P = .31), moderate physical activity (P = .56), vigorous physical activity (P = .26), MVPA (P = .66), steps per day (P = .64). No significant group by time interaction for self-reported measures of physical activity including, occupational physical activity (P = .88), active transport (P = .98), household physical activity (P = .52), recreational physical activity (P = .84). *Psychosocial outcomes* No significant group by time interaction for perceived benefits (P = .75), perceived barriers (P = .82), self-efficacy (P = .41), social support (P = .25). *Intervention Engagement* The number of visits halved from 824 visits in the first 3-weeks to 403 visits in the last 3-weeks. The average duration of visiting the app was 1:19 minutes in the first 3-weeks,	Attitude-social influence self-efficacy model	76%; good

						and 53 seconds in the last 3-weeks. Insufficient data to calculate effect sizes			
Walsh et al. (2016)	Ireland	55 participants 17-26 years Mean age: 20.55 years (2.07) 72.7% female	5-week, 2 group RCT Pre-intervention assessments: 1-week	*Mobile Application* Accupodo-Pro Pedometer App (commercially available): Tracking of daily step count and calories burnt; automatic feedback; step count history; goal-setting functionality; and goal achievement feedback *Intervention condition (n = 28)* Received Accupodo-Pro Pedometer App; instructions on how to use application; given physical activity goal (10, 000 steps per day); information on benefits of exercise *Control condition (n = 27)* Received Accupodo-Pro Pedometer App; application not made visible on phone and no instructions on how to use app; given physical activity goal (walking for 30 minutes per day); information on benefits of exercise	*Pre-intervention & 5 weeks* Accupodo-Pro Pedometer App Daily step count	*Physical activity outcomes* (*M* & *SD* not reported) Significant between-group difference in daily step count, $F(1, 53) = 4.30$, $P = .04$, $\eta_p^2 = 0.08$. Significant increase in step counts for from baseline to follow-up for both intervention condition, $t(27) = -6.14$, $P < .001$ and control condition, $t(26) = -2.25$, $P = .03$. Significantly higher increase in step count in the intervention condition (2393 steps) than the control condition (1101 steps), $t(53) = 2.07$, $P = .04$.	Capability, Motivation, Behaviour (COM-B) framework/ Behaviour Change Wheel	53%; fair

APPENDIX B

Summary of App Online Social Networking Studies

Reference	Country	Sample Characteristics	Study Design	Description of Intervention	Features of existing online social network	Physical Activity Outcome Measure(s)	Other Measures	Key Findings	Behaviour Change Theory	Study Quality & Risk of bias
Al Ayubi et al. (2014)	USA	13 participants 18-65 years Mean age: 32.15 years 76.9% female	4-week, within-subject pre-post design No social interaction: week 1 Social interaction enabled: week 2	*Mobile Application* Persuasive Social Network for Physical Activity Application (PersonA) (newly developed): Accelerometer to measure physical activity; goal setting; self-monitoring feedback on progress; peer comparison (compare performance with one other person and group average) *Intervention* Received PersonA	PersonA links to Facebook: Share physical activity data; post, like, comment on data; communicate	*Pre-intervention & 4 weeks* PersonA accelerometer Number of steps	*Pre-intervention & 4 weeks* App engagement PersonA recorded minutes of use	*Physical activity outcomes* Average number of steps increased from 4202 at baseline (no social interaction) to 6352 steps following the enablement of social interaction (*P*- value not reported). *Intervention engagement* The duration of system use increased from 419 minutes at baseline, to 465 minutes in week 2. Insufficient data to calculate effect sizes	Health Belief Model; Theory of reasoned action/ theory of planned behaviour; Elaboration Likelihood Model; Social Cognitive theory; Social supportive and health link theory; Users and gratification theory; Common bond and common identity theory; Technology Acceptance Model; Unified theory of acceptance and use of technology; Fogg Behavioural Model	60%; fair
Foster et al. (2010)	United Kingdom	10 participants Age range: not specified Mean age: not specified 90% female	21-days within-subject pre-post design, randomised cross-over Pre-intervention assessments: specific details not provided	*Mobile Application* Step Matron Application (newly designed) Monitoring of daily steps *Intervention* All participants engaged in the two conditions: 1. Socially enabled condition	Facebook View each other's step data, make comments and comparisons (rankings table)	*Pre-intervention & 5 days* Pedometer Number of steps	*Pre-intervention & 5 days* Google Analytics App logins and minutes of use	*Physical activity outcomes* Significantly higher number of steps when participants used the social condition (*M* = 42002, *SD* = 7040) than the non-social condition (*M* = 38132.1, *SD* = 7800) (*P* = .01, *d* = 0.52). *Intervention engagement*	Not reported	43%; poor

		Registered nurses		Received Step Matron Application; access to Facebook; wore pedometer 2. Non-socially enabled condition Received Step Matron Application; wore pedometer			1:46 minutes engaging with app during non-social condition. 2:37 minutes engaging with app during social enabled condition.			
Hurkmanns et al. (2018)	United Kingdom	102 participants (81 analysed) 18-65 years Mean age: 45 years (10.35) 69.7% female Overweight & obese (29 and 34 kg/m^2)	12-week, 4-group RCT Pre-intervention assessments: specific details not provided	*Mobile Application* Mobile weight loss application (newly developed): Advice on dietary patterns and physical activity; tracking of step count; self-monitoring; information on nutrition and physical activity; links to Facebook group *Intervention Conditions* *1*. Conventional condition; Individualised diet plan from a dietician; individualised physical activity plan; access to a dietician (week 1, 2 & 5); access to a physical activity coach (week 1, 2, 5 & 7) 2. App condition; Access to mobile application 3. Combination condition; Access to a dietician (week 1); access to a physical activity coach (week 1 & 7); access to mobile weight loss app	Facebook Group	*Pre-intervention & 12 weeks* Tri-axial accelerometer (ActiGraph) Time spent in moderate-to-vigorous physical activity (MVPA)	*Physical activity outcomes* No significant group by time interaction effects for MVPA (*P*- value not reported).	Not reported	73%; good

				Control Condition Wait list control						
Pope et al. (2019)	USA	10 participants ≥ 21 years Mean age: 45.80 years (10.23) 100% female Breast cancer survivors (no contraindications to physical activity)	10-week, within-subject pre-post design Pre-intervention assessments: 7 days Follow-up assessments: 1-week post-intervention	*Mobile Application* MapMyFitness Application (commercially available): Day to day physical activity diary *Intervention* MapMyFitness Application; Facebook page	Facebook Page: Education tips based on Social Cognitive Theory posted to page twice a week: Encouraged to post/ comment on the page	*Pre-intervention & follow-up* Accelerometer (worn on 7 consecutive days) Average daily minutes of sedentary behaviour, light physical activity and MVPA	*Pre-intervention & follow-up* Self-efficacy Scale Patient-centred Assessment and Counselling Questionnaire Social support Physical activity enjoyment Scale *Midpoint and post-intervention* Intervention engagement Self-report survey of MapMyFitness usage; frequency/duration of use Engagement with Facebook; posts generated and viewed	*Physical activity outcomes* Increase in average daily steps; baseline (*M* = 4930, *SD* = 1376); post-intervention (*M* = 6587, *SD* = 1229) (*d* = 1.27), and average daily MVPA; baseline (*M* = 26.8, *SD* = 13.8); post-intervention (*M* = 29.4, *SD* = 22.5) (*d* = 0.14). Decrease in average daily light physical activity from baseline (*M* = 94.9, *SD* = 44.8) to post-intervention (*M* = 86.7, *SD* = 64.7) (*d* = 0.15), and average daily sedentary behaviour; baseline (*M* = 493.7, *SD* = 176); post-intervention (*M* = 381, *SD* = 265.3) (*d* = 0.50). *Psychosocial outcomes* Increases in social support; baseline (*M* = 2.82, *SD* = 0.92); post-intervention (*M* = 3.38, *SD* = 1.24) (*d* = 0.51), self-efficacy; baseline (*M* = 72.89, *SD* = 29.70); post-intervention (*M* = 75.28, *SD* = 25.74) (*d* = 0.09), and enjoyment to exercise; baseline (*M* = 3.18, *SD* = 0.90); post-intervention (*M* = 3.33, *SD* = 0.80) (*d* = 0.13). *Intervention engagement* Frequency of MapMyFitness use; midpoint used 3.75 times per week; post-intervention used 4.34 times	Social Cognitive Theory	63%; fair

								per week. Duration of MapMyFitness use; midpoint used for 39.7 minutes per week; post-intervention used 35 minutes per week. 93% of participants viewed each Facebook post.		
Torquati, Kolbe-Alexander et al. (2018)	Australia	47 participants >18 years Mean age: 41.4years (12.1) 87% female Nurses	3-month, within-subject pre-post design Pre-intervention assessments: 7 days Follow-up assessments: 3 months post-intervention	*Mobile Application* Smartphone application (newly designed): Facilitate physical activity and diet goal-setting *Intervention* Smartphone application; Facebook Group; wore Pedometer	Private Facebook group Posting of motivational and inspirational quotes to be active/healthy	*Pre-intervention, 3 months & follow-up* Accelerometer (worn on 7 consecutive days) MVPA, daily steps, sedentary behaviour and light physical activity	*Pre-intervention, 3 months & follow-up* Social support scale Physical activity self-efficacy scale Intervention engagement Recorded use of intervention content; Viewing of pedometer and application instructions; views of Facebook posts	*Physical activity outcomes* Significant decrease in percentage of daily time spent in MVPA; baseline (*M* = 3.0, *SD* = 1.9); 3 months (*M* = 2.5, *SD* = 1.9); 6 months (*M* = 2.5, *SD* = 2.0) (*P* = .01, *d* = 0.26), and daily average steps; baseline (*M* = 8496, *SD* = 2528); 3 months (*M* = 8136, *SD* = 2395), 6 months (*M* = 7629, *SD* = 2342) (*P* = .05, *d* = 0.15). No significant changes in sedentary behaviour (*P* = .70) or light physical activity (*P* = .56). *Psychosocial outcomes* (*P* values not reported) No significant changes in self-efficacy or social support. *Intervention engagement* 68.4% used the app less than once a month or never. 47.4% engaged with the Facebook group at least once.	Social Cognitive Theory; Goal-setting Theory; Control Theory	65%; fair

APPENDIX C

Questionnaire (Studies 2-4)

INFORMATION SHEET

Title: Physical Activity & Online Social Networking

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Description of the study:

This study is part of the project titled: *'Physical Activity & Online Social Networking'*. This project will investigate the relationship between online social networking activities and physical activity. This project is supported by the College of Education, Psychology and Social Work and the College of Nursing and Health Sciences at Flinders University.

Purpose of the study:

The purpose of the study is to examine the relationship between online social networking and physical activity behaviours.

What will I be asked to do?

You will be asked to answer an online questionnaire examining online social networking and physical activity. The questions relate to your general levels of physical activity, engagement with online social networking, and your beliefs surrounding physical activity. The questionnaire will take approximately 30 minutes to complete. Participation is voluntary.

What benefit will I gain from being involved in this study?

Participation will give you first-hand experience in participating in research.

Will I be identifiable by being involved in this study?

We do not need your name and you will be anonymous.

Are there any risks or discomforts if I am involved?

While we do not believe there are any risks or discomforts associated with participation, if any of the items raise any issues that you would like to discuss you can contact Lifeline on 13 11 14.

How do I agree to participate?

Participation is voluntary. If you are interested in participating in this study, please click on the link below. Upon completion, your data will be sent to a secure, password protected server that can only be accessed by the researchers.

Recognition of contribution / time

If you would like to participate, in recognition of your contribution and participation time, you will go in the draw to win one of five $25 Coles/Myer vouchers.

How will I receive feedback?

On project completion, outcomes of the project will be given to all participants via email.

Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 8232). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au

By selecting the option to move the survey forward you are giving consent to participate in this study.

Section A: Demographic Information

For each of the following questions, please fill out your response:

Gender

- ◯ Female
- ◯ Male
- ◯ Other
- ◯ Do not wish to disclose

Age (years):

Please indicate your cultural background

- ◯ Caucasian
- ◯ Indigenous Australian or Torres Straight Islander
- ◯ Asian
- ◯ African
- ◯ Middle-Eastern
- ◯ Indian
- ◯ Other (please specify)

The following questions are concerned with your current physical activity. Please fill in the survey questions if applicable.

Please indicate if you currently engage in any type of **physical activity/sport**.

- ◯ Yes
- ◯ No

Please list the **main** type of physical activity/sport that you currently participate in.

How **long** do you spend doing this activity/ sport on each occasion?
Please specify in **minutes.**

How **often** do you partake in this activity or sport per week?

Are there any other types of **physical activity/sport** that you engage in currently?

- ◯ Yes
- ◯ No

Please list the type of **physical activity/sport** that you currently participate in.

How **long** do you spend doing this activity/ sport on each occasion?
Please specify in **minutes.**

How **often** do you partake in this activity or sport per week?

Are there any other types of **physical activity/sport** that you engage in currently?

- ◯ Yes
- ◯ No

Please list the type of **physical activity/sport** that you currently participate in.

How **long** do you spend doing this activity/ sport on each occasion?
Please specify in **minutes.**

How **often** do you partake in this activity or sport per week?

Section B. Current Physical Activity Application Use

In the next set of questions we are interested in your **current** use of physical activity apps.

Are you **currently** using a physical activity app?

Physical activity apps may include apps that track/monitor physical activity (e.g., steps, distance, active minutes) or provide guided training/workouts.

- ◯ Yes
- ◯ No

Please state the **main physical activity app** you are **currently** using, the physical activity/sport you are using this app for, and how many times per week you use this app.

Main physical activity app you are currently using (e.g. Strava)	
Physical activity/sport this app is used for (e.g. cycling)	
Times used per week	

Does the **main physical activity app** you are **currently** using incorporate any social features?

Social features may allow the following; sharing posts related to your physical activity, commenting/liking others' physical activity posts, comparing your physical activity data with others or engaging in competitions.

- ◯ Yes
- ◯ No
- ◯ Unsure

Do you use any of the social features incorporated into the **main physical activity app** you are **currently** using?

- ◯ Yes
- ◯ No

Within the **main physical activity app** you are **currently** using, how often do you **share** posts relating to your physical activity performance with any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	◯	◯	◯	◯	◯	◯
Family	◯	◯	◯	◯	◯	◯
Close friend	◯	◯	◯	◯	◯	◯
Peers	◯	◯	◯	◯	◯	◯
Public app community	◯	◯	◯	◯	◯	◯
Work colleagues	◯	◯	◯	◯	◯	◯
Social networking platforms (e.g., Facebook, Instagram)	◯	◯	◯	◯	◯	◯
Other (please specify)	◯	◯	◯	◯	◯	◯

Within the **main physical activity app** you are **currently** using, how often do you **Like/Kudos/Cheer** and/or **provide positive comments** on physical activity posts from any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you are **currently** using, how often do you **receive Likes/Kudos/Cheers** and/or **positive comments** on your **own** physical activity posts from any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you are **currently** using, how often do engage in **competitions** with any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you are **currently** using, how often do you **compare** your physical activity data with any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Section C. Physical Activity & Social Networking Platforms

In the next set of questions we are interested in your behaviour on **social networking platforms** (e.g., Facebook, Instagram) in relation to your physical activity.

How often do you **share** physical activity posts on the following social networking platforms?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

How often do you **like** and/or provide **positive comments** on physical activity posts from **other people** on the following social networking platforms?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

How often do you **receive likes** and/or **positive comments** on your **own** physical activity posts on the following social networking platforms?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very often	N/A
Other (please specify)						
Other (please specify)						

How often do you **compare** your physical activity to others' physical activity posts on the following social networking platforms?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook						
Instagram						
Twitter						
Other (please specify)						
Other (please specify)						

Section D. Social Support for Exercise Behaviours Scale

In the next set of questions we are interested in your general physical activity behaviour.

Please rate how often your **friends** (left column) and **family** (right column) have done the following things in the **last month.**

	Friends					**Family**				
	Never	Rarely	A few times	Often	Very Often	Never	Rarely	A few times	Often	Very Often
Exercised with me.										
Offered to exercise with me.										

	Friends					Family				
	Never	Rarely	A few times	Often	Very Often	Never	Rarely	A few times	Often	Very Often
Gave me helpful reminders to exercise ("Are you going to exercise tonight?").	○	○	○	○	○	○	○	○	○	○
Gave me encouragement to stick with my exercise program.	○	○	○	○	○	○	○	○	○	○
Changed their schedule so we could exercise together.	○	○	○	○	○	○	○	○	○	○
Discussed exercise with me.	○	○	○	○	○	○	○	○	○	○
Complained about the time I spend exercising.	○	○	○	○	○	○	○	○	○	○
Criticised me or made fun of me for exercising.	○	○	○	○	○	○	○	○	○	○
Gave me rewards for exercising (bought me something or gave me something I like).	○	○	○	○	○	○	○	○	○	○
Planned for exercise on recreational outings.	○	○	○	○	○	○	○	○	○	○
Helped plan exercise around my activities.	○	○	○	○	○	○	○	○	○	○
Asked me for ideas on how they can get more exercise.	○	○	○	○	○	○	○	○	○	○
Talked about how much they like exercise.	○	○	○	○	○	○	○	○	○	○

Section E. Physical Activity Self-Efficacy Scale

How certain are you that you could overcome the following barriers?

	Very uncertain	Rather uncertain	Rather certain	Very certain
I can manage to carry out my exercise intentions, even when I have worries and problems.	○	○	○	○
I can manage to carry out my exercise intentions, even if I feel depressed.	○	○	○	○
I can manage to carry out my exercise intentions, even when I feel tense.	○	○	○	○
I can manage to carry out my exercise intentions, even when I am tired.	○	○	○	○
I can manage to carry out my exercise intentions, even when I am busy.	○	○	○	○

Section F. Behaviour Regulation in Exercise Questionnaire

Using the scale below, please indicate to what extent each of the following statements are true for you.

	Not true for me		Sometimes true for me		Very true for me
	0	1	2	3	4
I exercise because other people say I should.	○	○	○	○	○
I feel guilty when I don't exercise.	○	○	○	○	○
I value the benefits of exercise.	○	○	○	○	○
I exercise because it's fun.	○	○	○	○	○
I don't see why I should have to exercise.	○	○	○	○	○

	Not true for me		Sometimes true for me		Very true for me
	0	1	2	3	4
I take part in exercise because my friends/family/partner say I should.	○	○	○	○	○
I feel ashamed when I miss an exercise session.	○	○	○	○	○
It's important to me to exercise regularly.	○	○	○	○	○
I can't see why I should bother exercising.	○	○	○	○	○
I enjoy my exercise sessions.	○	○	○	○	○
I exercise because others will not be pleased with me if I don't.	○	○	○	○	○
I don't see the point in exercising.	○	○	○	○	○
I feel like a failure when I haven't exercised in a while.	○	○	○	○	○
I think it is important to make the effort to exercise regularly.	○	○	○	○	○
I find exercise a pleasurable activity.	○	○	○	○	○
I feel under pressure from my friends/family to exercise.	○	○	○	○	○
I get restless if I don't exercise regularly.	○	○	○	○	○
I get pleasure and satisfaction from participating in exercise.	○	○	○	○	○
I think exercising is a waste of time.	○	○	○	○	○

Section G. Competitiveness Index

The following questions ask about competitiveness in different situations. Please indicate the degree to which you agree or disagree with each of the following statements below.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I like competition.	○	○	○	○	○
I am a competitive individual.	○	○	○	○	○
I enjoy competing against an opponent.	○	○	○	○	○
I don't like competing against other people.	○	○	○	○	○
I get satisfaction from competing with others.	○	○	○	○	○
I find competitive situations unpleasant.	○	○	○	○	○
I dread competing against other people.	○	○	○	○	○
I try to avoid competing with others.	○	○	○	○	○
I often try to outperform others.	○	○	○	○	○

Section H. Iowa-Netherlands Comparison Orientation Measure

The following questions ask about making comparisons with other people. For each question, please indicate how much you agree or disagree with each statement below.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I often compare how my loved ones (boy or girlfriend, family members, etc) are doing with how others are doing.	○	○	○	○	○
I always pay a lot of attention to how I do things compared with how others do things.	○	○	○	○	○
If I want to find out how well I have done something, I compare what I have done with how others have done.	○	○	○	○	○

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I often compare how I am doing socially (e.g., social skills, popularity) with other people.	○	○	○	○	○
I am not the type of person who compares often with others.	○	○	○	○	○
I often compare myself with others with respect to what I have accomplished in life.	○	○	○	○	○
I often like to talk with others about mutual opinions and experiences.	○	○	○	○	○
I often try to find out what others think who face similar problems as I face.	○	○	○	○	○
I always like to know what others in a similar situation would do.	○	○	○	○	○
If I want to learn more about something, I try to find out what others think about it.	○	○	○	○	○
I never consider my situation in life relative to that of other people.	○	○	○	○	○

Section I

Please select the day, month and year of your birth date below:

Day	
Month	
Year	

You have now come to the end of the questionnaire, and will be placed in the draw to win one of five $25 gift Coles/Myer gift vouchers.

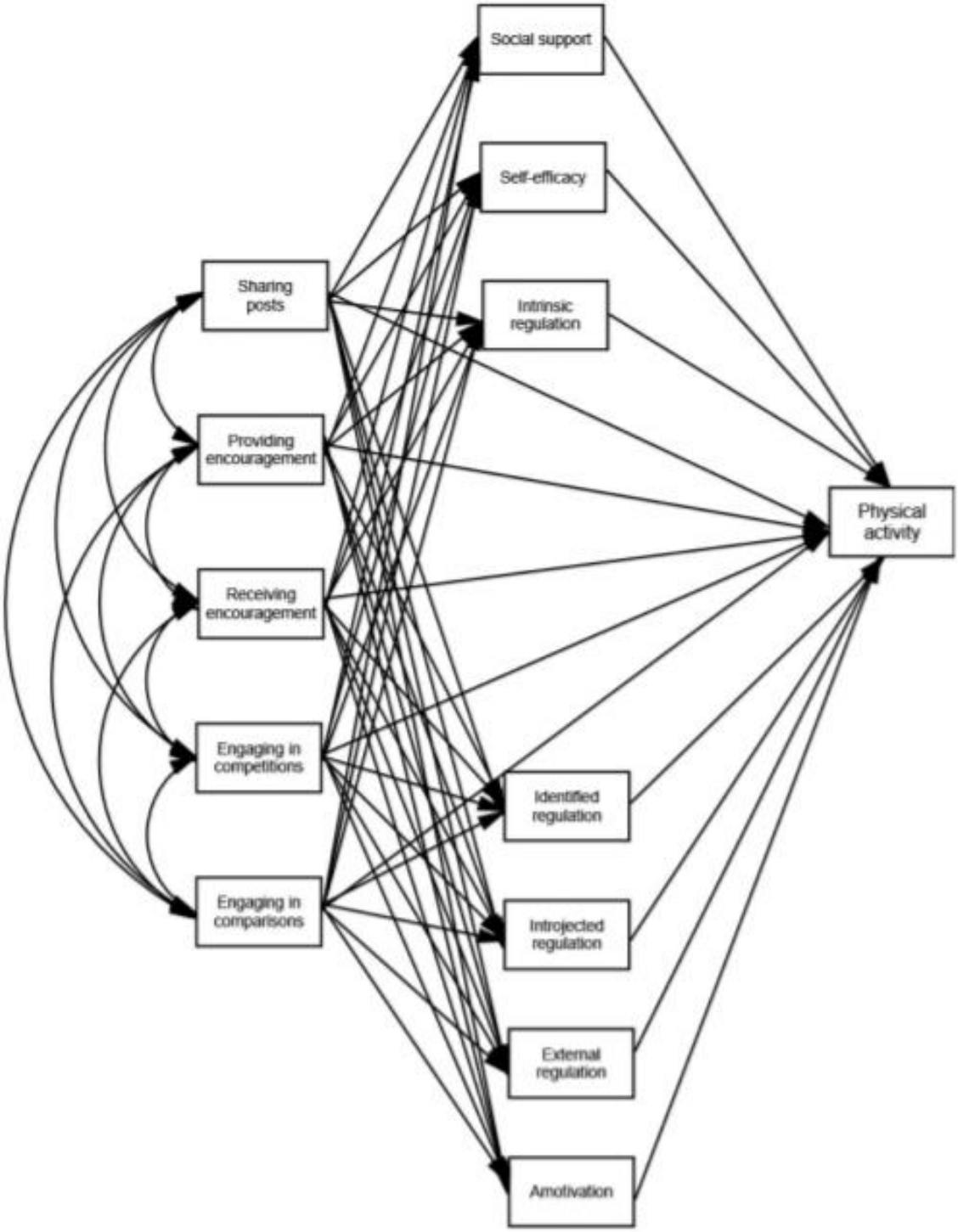
If you have any queries about the project please contact Jasmine Petersen (jasmine.petersen@flinders.edu.au).

Thank you for your time!

Do not exit this questionnaire, please click **Finish**.

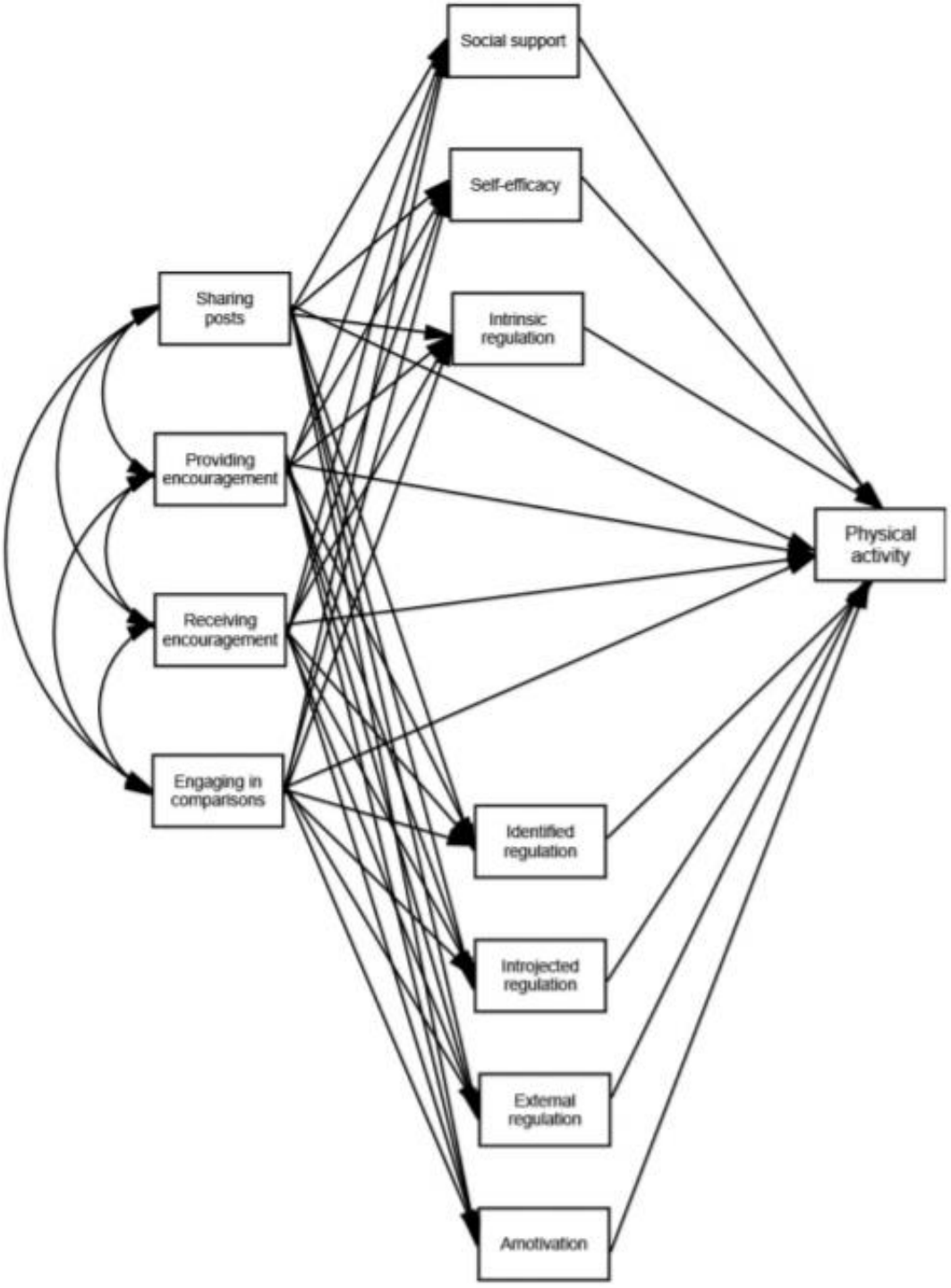
APPENDIX D

Structural Equation Model simultaneously examining all features of app-specific communities



APPENDIX E

Structural Equation Model simultaneously examining all features of existing social networking platforms



APPENDIX F

Questionnaire (Study 5)

INFORMATION SHEET

Title: Physical Activity & Online Social Networking during COVID-19

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Description of the study:

This study is part of the project titled: *'Physical Activity & Online Social Networking'*. This project will investigate physical activity engagement, physical activity app use and online social networking during COVID-19. This project is supported by the College of Education, Psychology and Social Work and the College of Nursing and Health Sciences at Flinders University.

Purpose of the study:

The purpose of the study is to examine physical activity engagement, physical activity app use and online social networking during COVID-19.

What will I be asked to do?

You will be invited to complete an online questionnaire which will take approximately 30 minutes to complete. The questionnaire is very similar to the one that you have completed in the past, however, the questions are now specific to the COVID-19 lockdown period (April/May this year). The questionnaire

will measure; physical activity behaviour, engagement with physical activity apps and online social networking, beliefs surrounding physical activity, and psychological well-being (including questions regarding your mood). Participation is voluntary.

What benefit will I gain from being involved in this study?

Participation will give you first-hand experience in participating in research.

Will I be identifiable by being involved in this study?

We do not need your name and you will be anonymous.

Are there any risks or discomforts if I am involved?

While we do not believe there are any risks or discomforts associated with participation, if any of the questionnaire items raise any issues that you would like to discuss please contact Lifeline on 13 11 14 or your General Practitioner.

How do I agree to participate?

Participation is voluntary. If you are interested in participating in this study, please click on the link below. Upon completion, your data will be sent to a secure, password protected server that can only be accessed by the researchers.

Recognition of contribution / time

If you would like to participate, in recognition of your contribution and participation time, you will go in the draw to win one of five $25 Coles/Myer vouchers.

How will I receive feedback?

On project completion, outcomes of the project will be given to all participants via email.

Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 8232). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au

By selecting the option to move the survey forward you are giving consent to participate in this study.

For each of the following questions, please fill out your response:

Gender:

- ◯ Female
- ◯ Male
- ◯ Other
- ◯ Do not wish to disclose

Age (years):

Please indicate your cultural background

- ◯ Caucasian
- ◯ Indigenous Australian or Torres Straight Islander
- ◯ Asian
- ◯ African
- ◯ Middle-Eastern
- ◯ Indian
- ◯ Other (please specify)

Please provide your current postcode.

Please enter your:

Height (cm)

Weight (kg)

The following questions are concerned with your physical activity **during the COVID-19 lockdown (April/May).** Please fill in the survey questions if applicable.

Please indicate if you engaged in any type of physical activity/sport **during the COVID-19 lockdown (April/May).**

- ◯ Yes
- ◯ No

Please list the **main** type of physical activity/sport that you engaged in **during the COVID-19 lockdown (April/May).**

How **often** did you partake in this activity/ sport in a typical week **during the COVID-19 lockdown (April/May)?**

How **long** do you spend doing this activity/ sport on each occasion?
Please specify in **minutes.**

Are there any other types of **physical activity/sport** that you engaged in **during the COVID-19 lockdown (April/May)?**

- ◯ Yes
- ◯ No

Please list the type of **physical activity/sport** that you engaged in **during the COVID-19 lockdown (April/May).**

How **often** did you partake in this activity/sport in a typical week **during the COVID-19 lockdown (April/May)?**

How **long** did you spend doing this activity/sport on each occasion?
Please specify in **minutes.**

Are there any other types of **physical activity/sport** that you engaged in **during the COVID-19 lockdown (April/May)?**

- ◯ Yes
- ◯ No

Please list the type of **physical activity/sport** that you engaged in **during the COVID-19 lockdown (April/May).**

How **often** did you partake in this activity/ sport in a typical week **during the COVID-19 lockdown (April/May)?**

How **long** do you spend doing this activity/ sport on each occasion?
Please specify in **minutes.**

Please indicate which of the following best describes your physical activity levels **during the COVID-19 lockdown (April/May).**

- ◯ I was much more physically active than usual
- ◯ I was a little more physically active than usual
- ◯ I maintained my usual levels of activity
- ◯ I was a little less physically active than usual
- ◯ I was much less physically active than usual
- ◯ I ceased physical activity altogether

Section B. Current Physical Activity Application Use

In the next set of questions we are interested in your use of physical activity apps **during the COVID-19 lockdown (April/May).**

Did you use a physical activity app **during the COVID-19 lockdown (April/May)?**

Physical activity apps may include apps that track/monitor physical activity (e.g., steps, distance, active minutes) or provide guided training/workouts.

- ◯ Yes
- ◯ No

Did you use this physical activity app in conjunction with a wearable activity tracker **during the COVID-19 lockdown (April/May)?**

A wearable activity tracker refers to a tracking device that can either be attached to your clothing or worn on the body (e.g., wrist). A wearable activity tracker **does not** include those built into your smartphone.

- ◯ Yes
- ◯ No

Please indicate the brand of the wearable activity tracker you used **during the COVID-19 lockdown (April/May).**

- ◯ Fitbit
- ◯ Garmin
- ◯ Apple
- ◯ Jawbone
- ◯ Samsung
- ◯ Polar
- ◯ Other (please specify) _____

We are now interested in the **physical activity app** you used most frequently (your main physical activity app) **during the COVID-19 lockdown (April/May).**

Please state the **main physical activity app** you used **during the COVID-19 lockdown (April/May)**, the physical activity/sport you used this app for, how many times in a typical week you used this app, and when you started using this app (month and year).

Main physical activity app used during the COVID-19 lockdown (e.g., Strava)	
Physical activity/sport this app was used for (e.g., cycling)	
Times used per week	
When you started using this app (month and year) (e.g., Feb 2020)	

Did the **main physical activity app** you used **during the COVID-19 lockdown (April/May)** incorporate any social features?

Social features may allow the following; sharing posts related to your physical activity, commenting/liking others' physical activity posts, comparing your physical activity data with others or engaging in competitions.

- ◯ Yes
- ◯ No
- ◯ Unsure

Did you use any of the social features incorporated into the **main physical activity app** used **during the COVID-19 lockdown (April/May)?**

- ○ Yes
- ○ No

The next set of questions will ask you about your use of the social features **within** the **main physical activity app** you used **during the COVID-19 lockdown (April/May).**

Within the **main physical activity app** you used **during the COVID-19 lockdown (April/May)**, how often did you **share** posts relating to your physical activity performance with any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Social networking platforms (e.g., Facebook, Instagram)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you **used during the COVID-19 lockdown (April/May)**, how often did you **Like/Kudos/Cheer** and/or **provide positive comments** on physical activity posts from any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very often	N/A
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you used **during the COVID-19 lockdown (April/May)**, how often did you **receive Likes/Kudos/Cheers** and/or **positive comments** on your **own** physical activity posts from any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you used **during the COVID-19 lockdown (April/May)**, how often did you engage in **competitions** with any of the following?

	Never	Rarely	Sometimes	Often	Very often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Within the **main physical activity app** you used **during the COVID-19 lockdown (April/May)**, how often did you **compare** your physical activity data with any of the following?

	Never	Rarely	Sometimes	Often	Very Often	N/A
Partner	○	○	○	○	○	○
Family	○	○	○	○	○	○
Close friend	○	○	○	○	○	○
Peers	○	○	○	○	○	○
Members of a public app community	○	○	○	○	○	○
Work colleagues	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

Section C: Physical Activity & Social Networking Platforms

In the next set of questions we are interested in your behaviour on **social networking platforms** (e.g., Facebook, Instagram) in relation to physical activity **during the COVID-19 lockdown (April/May)**.

How often did you **share** physical activity posts on the following social networking platforms **during the COVID-19 lockdown (April/May)**?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
TikTok	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

How often did you **like and/or provide positive comments** on others' physical activity posts from the following social networking platforms **during the COVID-19 lockdown (April/May)?**

	Never	Rarely	Sometimes	Often	Very Often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
TikTok	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

How often did you **receive likes and/or positive comments** on your **own** physical activity posts on the following social networking platforms **during the COVID-19 lockdown (April/May)?**

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
TikTok	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

How often did you **compare** your physical activity to others' physical activity posts on the following social networking platforms **during the COVID-19 lockdown (April/May)**?

	Never	Rarely	Sometimes	Often	Very often	N/A
Facebook	○	○	○	○	○	○
Instagram	○	○	○	○	○	○
Twitter	○	○	○	○	○	○
TikTok	○	○	○	○	○	○
Other (please specify)	○	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very often	N/A
Other (please specify)	○	○	○	○	○	○

Section D. Social Support for Exercise Behaviours Scale

In the next set of questions we are interested in the support you received and your general thoughts about physical activity behaviour **during the COVID-19 lockdown (April/May).**

Please rate how often your **friends** (left column) and **family** (right column) have done the following **during the COVID-19 lockdown (April/May).**

	Friends					**Family**				
	Never	Rarely	A few times	Often	Very often	Never	Rarely	A few times	Often	Very often
Exercised with me.	○	○	○	○	○	○	○	○	○	○
Offered to exercise with me.	○	○	○	○	○	○	○	○	○	○
Gave me helpful reminders to exercise ("Are you going to exercise tonight?").	○	○	○	○	○	○	○	○	○	○
Gave me encouragement to stick with my exercise program.	○	○	○	○	○	○	○	○	○	○
Changed their schedule so we could exercise together.	○	○	○	○	○	○	○	○	○	○
Discussed exercise with me.	○	○	○	○	○	○	○	○	○	○
Complained about the time I spend exercising.	○	○	○	○	○	○	○	○	○	○
Criticised me or made fun of me for exercising.	○	○	○	○	○	○	○	○	○	○

	Friends					Family				
	Never	Rarely	A few times	Often	Very often	Never	Rarely	A few times	Often	Very often
Gave me rewards for exercising (bought me something or gave me something I like).	○	○	○	○	○	○	○	○	○	○
Planned for exercise on recreational outings.	○	○	○	○	○	○	○	○	○	○
Helped plan exercise around my activities.	○	○	○	○	○	○	○	○	○	○
Asked me for ideas on how they can get more exercise.	○	○	○	○	○	○	○	○	○	○
Talked about how much they like exercise.	○	○	○	○	○	○	○	○	○	○

Section E. Physical Activity Self-Efficacy Scale

How certain are you that you were able to overcome the following barriers **during the COVID-19 lockdown (April/May)?**

	Very uncertain	Rather uncertain	Rather certain	Very certain
I managed to carry out my exercise intentions, even when I had worries and problems.	○	○	○	○
I managed to carry out my exercise intentions, even when I felt depressed.	○	○	○	○
I managed to carry out my exercise intentions, even when I felt tense.	○	○	○	○
I managed to carry out my exercise intentions, even when I was tired.	○	○	○	○

	Very uncertain	Rather uncertain	Rather certain	Very certain
I managed to carry out my exercise intentions, even when I was busy.	○	○	○	○

Section F. Behaviour Regulation in Exercise Questionnaire

Using the scale below, please indicate to what extent each of the following statements were true for you **during the COVID-19 lockdown (April/May)**

	Not true for me		Sometimes true for me		Very true for me
	0	1	2	3	4
I exercised because other people said I should.	○	○	○	○	○
I felt guilty when I didn't exercise.	○	○	○	○	○
I valued the benefits of exercise.	○	○	○	○	○
I exercised because it was fun.	○	○	○	○	○
I didn’t see why I should have to exercise.	○	○	○	○	○
I took part in exercise because my friends/family/partner said I should.	○	○	○	○	○
I felt ashamed when I missed an exercise session.	○	○	○	○	○
It was important to me to exercise regularly.	○	○	○	○	○
I didn’t see why I should bother exercising.	○	○	○	○	○
I enjoyed my exercise sessions.	○	○	○	○	○
I exercised because others would not be pleased with me if I didn’t.	○	○	○	○	○

	Not true for me		Sometimes true for me		Very true for me
	0	1	2	3	4
I didn't see the point in exercising.	○	○	○	○	○
I felt like a failure when I hadn't exercised in a while.	○	○	○	○	○
I thought it was important to make the effort to exercise regularly.	○	○	○	○	○
I found exercise a pleasurable activity.	○	○	○	○	○
I felt under pressure from my friends/family to exercise.	○	○	○	○	○
I got restless if I didn't exercise regularly.	○	○	○	○	○
I got pleasure and satisfaction from participating in exercise.	○	○	○	○	○
I thought exercising was a waste of time.	○	○	○	○	○

Section G. Depression Anxiety Stress Scale

Please read each statement and indicate how much the statement applied to you **during the COVID-19 lockdown (April/May).**

	Did not apply to me at all	Applied to me to some degree, or some of the time	Applied to me to a considerable degree, or a good part of time	Applied to me very much, or most of the time
	0	1	2	3
I found it hard to wind down.	○	○	○	○
I was aware of dryness of my mouth.	○	○	○	○
I couldn't seem to experience any positive feeling at all.	○	○	○	○

	Did not apply to me at all	Applied to me to some degree, or some of the time	Applied to me to a considerable degree, or a good part of time	Applied to me very much, or most of the time
	0	1	2	3
I experienced breathing difficulty (e.g., excessively rapid breathing, breathlessness in the absence of physical exertion).	○	○	○	○
I found it difficult to work up the initiative to do things.	○	○	○	○
I tended to over-react to situations.	○	○	○	○
I experienced trembling (e.g., in the hands).	○	○	○	○
I felt that I was using a lot of nervous energy.	○	○	○	○
I was worried about situations in which I might panic and make a fool of myself.	○	○	○	○
I felt that I had nothing to look forward to.	○	○	○	○
I found myself getting agitated.	○	○	○	○
I found it difficult to relax.	○	○	○	○
I felt down-hearted and blue.	○	○	○	○
I was intolerant of anything that kept me from getting on with what I was doing.	○	○	○	○
I felt I was close to panic.	○	○	○	○
I was unable to become enthusiastic about anything.	○	○	○	○
I felt I wasn't worth much as a person.	○	○	○	○

	Did not apply to me at all	Applied to me to some degree, or some of the time	Applied to me to a considerable degree, or a good part of time	Applied to me very much, or most of the time
	0	1	2	3
I felt that I was rather touchy.	○	○	○	○
I was aware of the action of my heart in the absence of physical exertion (e.g., sense of heart rate increase, heart missing a beat).	○	○	○	○
I felt scared without any good reason.	○	○	○	○
I felt that life was meaningless.	○	○	○	○

Section H.

You have now come to the end of the questionnaire and will be placed in the draw to win one of five $25 gift Coles/Myer gift vouchers.

If you have any queries about the project, please contact Jasmine Petersen (jasmine.petersen@flinders.edu.au).

Thank you for your time!

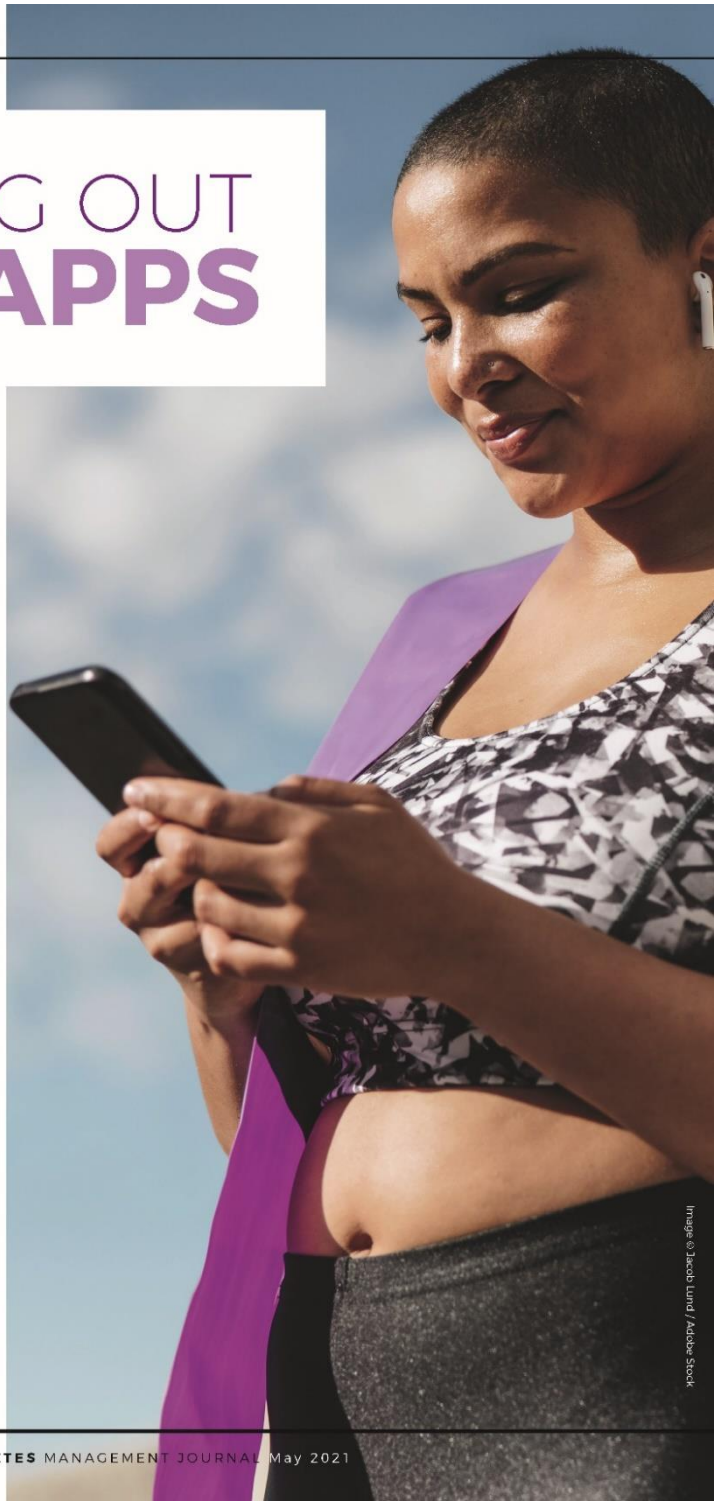
Do not exit this questionnaire, please click **Finish**.

APPENDIX G

Invited feature article (based on this program of research) published in Diabetes Management Journal

TECHNOLOGY

STEPPING OUT WITH APPS



Physical activity is essential for physical and mental health, reducing the risk of cardiovascular disease, obesity, premature mortality, depression, and anxiety.[1] Physical activity has long been considered the cornerstone of diabetes management,[2] with many additional benefits for people with diabetes including reduced insulin resistance and improved glycaemic management, blood lipid profile, endothelial function, blood pressure and beta cell function.[3,4] Nevertheless, many individuals with diabetes do not meet the recommended levels of physical activity (150 min of moderate-to-vigorous intensity activity per week).[5]

Barriers for people with diabetes to be active include reduced confidence in one's ability to perform physical activity (self-efficacy), lack of time, knowledge and motivation, insufficient social support, physical constraints (e.g., pain) and limited availability of facilities.[6-8] The COVID-19 pandemic has presented further challenges for people with diabetes to be physically active as they are classified as a 'high risk' group,[9] and therefore may be required to engage in prolonged precautionary measures including physical distancing, home confinement, and quarantine.

A growing body of research reports significant reductions in physical activity among individuals with diabetes during COVID-19.[10-12] There is an urgent need to identify strategies to support physical activity engagement for people with diabetes to enhance health outcomes, both during and following the COVID-19 pandemic.

Apps for Diabetes Management

Smartphone apps can benefit people with diabetes. Smartphone apps include free apps and some with optional features for purchase (see Table 1). They simultaneously target a range of diabetes self-management

Petersen JM, Kemps E, Lewis LK, Prichard I. (2021). Stepping out with apps - evidence-based guide to recommending physical activity apps. *Diabetes Management Journal*.

Physical activity is critical to optimising health outcomes for people with diabetes. Flinders University researchers **Jasmine Petersen, A/Prof. Lucy Lewis, A/Prof. Ivanka Prichard** and **Prof Eva Kemps** provide a practical guide to recommending physical activity apps.

behaviours,[13] for example blood glucose monitoring, physical activity and nutrition.[14] There are also apps that exclusively target physical activity behaviour, which track physical activity behaviour and/or provide guided workouts or training programs.[15,16]

Physical activity apps which target a single health behaviour, like physical activity, have been found to be more effective than apps that target multiple health behaviours.[17]

Benefits of Physical Activity Apps

Physical activity apps are affordable, convenient and can be used at home. They are also highly accessible. One 2018 survey suggests 89% of Australians aged 18-75 years own smartphones.[18]

This provides an ideal opportunity to support physical activity engagement in the broader population, including rural and remote areas, which have a high prevalence of diabetes,[19] and potentially fewer opportunities to engage in physical activity. Physical activity apps have been shown to be accepted by the population at large (including adults ≥65 years),[20,21] with increasing adoption of apps across all age groups.[22] The apps incorporate behaviour change techniques (e.g., feedback and monitoring, goal setting, social support)[23] that are known to promote physical activity in the general adult population[24] and older adults in particular.[25]

This is important given the age-related decline in physical activity in individuals with diabetes.[5] The use of physical activity apps has been linked to higher physical activity engagement, both during COVID-19 and non-pandemic times.[17,21,26,27] Physical activity apps also positively influence motivation and beliefs in one's ability to perform physical activity (self-efficacy). These psychological constructs are strong predictors of physical activity and central to behaviour change theories.[21] Physical activity apps are particularly valuable for individuals with diabetes because lack of social support, self-efficacy, and motivation are documented key barriers to physical activity engagement in this population.[6-8]

An overview of ten free physical activity apps that are popular (≥2000 downloads in February 2021), and achieved a high rating (≥4; 1-5 scale) by a large number of users (>1000 users) is provided in Table 1.

Social Features of Physical Activity Apps

A growing body of research demonstrates that social support is critical to the adoption and maintenance of diabetes self-management, including physical activity.[28] Social support is a precursor to self-efficacy. And this is the strongest predictor of physical activity

Table 1. Overview of free physical activity apps that are widely used and highly rated

	Freemium $	Tracking capabilities	Guided workouts or training programs	Promotes aerobic activity	Promotes resistance activity	App community	Connects to social networking platform(s)
Garmin Connect	–	+	+	+	+	+	+
Strava Training: Run & Ride	+	+	$	+	+	+	+
Nike Run Club	+	+	+	+	–	+	+
Runkeeper	+	+	$	+	–	+	+
Pacer Pedometer	+	+	+	+	+	+	+
Seven - Quick at Home Workouts	+	+	+	+	+	+	+
Walking Running Tracker	+	+	$	+	–	–	+
Map My Run by Under Armour	+	+	+	+	+	+	+
Home Workout - No Equipment	+	+	+	+	+	–	+
StepsApp Pedometer	–	+	–	+	–	–	+

Note. [+] incorporates the functionality. [-] does not incorporate the functionality. [$] freemium version incorporates the functionality. All listed physical activity apps are available from Apple iTunes (iOS) and Google Play (Android). $Freemium: free apps that incorporate additional functionality that is only unlocked by purchasing the full version.

in the broader population[29] and those with diabetes.[30,31]

Online social networks are a novel tool to foster social support. They can help overcome many challenges associated with face-to-face support and afford several advantages, including greater accessibility of immediate and continuous support, and wide reach. The support of online social networks emulates the interpersonal support achieved through face-to-face interactions.[32]

Many physical activity apps incorporate social networking functionalities that facilitate supportive interactions with other users (app communities such as running/walking groups) or connections to existing social networking platforms (e.g., Facebook).[33] These features are particularly valuable in fostering support from other persons with diabetes, sharing similar experiences of physical activity, as well as those without diabetes but sharing a behavioural goal like physical activity engagement.

The social networking features of physical activity apps support engagement in physical activity in the general population.[17,21,26,27] A systematic review found social networking platforms valuable in increasing engagement with physical activity apps.[17] Higher engagement, in turn, is consistently associated with enhanced effectiveness of the app.[34]

The use of social networking features (i.e., app communities and social networking platforms) in physical activity apps is also associated with increased engagement in physical activity.[21,27] Australian adults participating in app communities and associated social networking during the initial COVID-19 lockdown had higher rates of engagement in physical activity.[26]

Strava is a widely used app that allows users to share tracked physical activity such as details of a run with close networks (such as friends, family or peers), public app communities including running groups composed of unknown others, and/or social networking platforms.

Other research shows how to effectively leverage these social features to promote engagement in physical activity.[21,35] Sharing tracked physical activity to social networking platforms generates positive encouragement, promoting physical activity. This facilitates increased social support, motivation, and self-efficacy.[21,35]

Accordingly, the use of physical activity apps and their associated social features should be promoted. They provide a novel approach to overcome the lack of social support commonly reported by people with diabetes,[6-8] particularly during the current pandemic when opportunities for social interactions are often restricted.

Safety

Pre-exercise screening[36] before individuals engage in physical activities reduces the risk of an adverse event. Sports Medicine Australia have provided a free screening tool found here: http://bit.ly/PreExerciseScreening. A guide to app safety can be found at http://bit.ly/DigitalHealthGuide and accessed via your PHN or local library.

The authors report no conflict of interest.

References: www.diabetesaustralia.com.au/diabetes-management-journal.

mooee / Adobe Stock

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A/Prof. Ivanka Prichard, PhD is an Associate Professor at Flinders University.

PRACTICE TAKEAWAYS:

1. Sharing tracked physical activity with other app users and/or networks on social networking platforms encourages people to exercise.
2. Physical activity apps that incorporate guided workouts or training programs should be evidence-based or developed in consultation with a reputable source (e.g., health professional/s).
3. Consider the specific type(s) of physical activity (e.g., aerobic exercise, resistance exercise) targeted by each app to support individuals in meeting their physical activity guidelines.
4. Choose apps which incorporate content and functionality tailored to an individual, rather than a one-size fits all approach. App suitability varies according to one's preferences, age, or gender.
5. Physical activity apps are not a stand-alone tool caring for people with diabetes but supplement in-person clinical interactions to optimise health outcomes.