Video Gaming and Health-Related Components of Fitness

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List of Abbreviations

Active-VG – Active Video Gaming

BF% - Body Fat Percentage

BMI – Body Mass Index

HRCoF – Health-related components of fitness

E-athletes – Esport Athletes

EDF – Effective Degrees of Freedom

Esports – Electronic Sports

FPS – First Person Shooter

GAM – Generalised Additive Modelling

METs – Metabolic Equivalents

MMORPG – Massive Multiplayer Online Role-Playing Game

MOBA – Multiplayer Online Battle Arena

NOS – Newcastle-Ottawa Scale

PA – Physical Activity

PAR-Q – Physical Activity Readiness Questionnaire

PEBL – Psychology Experiment Building Language

RT – Reaction Time

VG – Video Gaming

VGP – Video Gaming Players

VR – Virtual Reality

Abstract

Video gaming (VG) can be a highly sedentary activity and has significantly increased in popularity over the past decade. Sedentary behaviour is related to a number of health issues, for example, weight gain, all-cause and cardiovascular mortality, and type 2 diabetes mellitus. Therefore, it is imperative to evaluate the physiological and cognitive health-related components of fitness (HRCoF) of VG players (VGP). Therefore, the primary aim of this thesis was to investigate the relationship between VG and physiological and cognitive HRCoF. Chapter 2 comprised of a systematic literature review, that aimed to collate and synthesise the current literature on the implications of VG across HRCoF within E-athletes and habitual-VGP. Six articles were examined with links between VG and HRCoF and methodologies used. This Chapter highlighted extensive gaps within the research literature, adult male dominated samples with limited HRCoF being measured, and identified that VG participation is associated with faster reaction times. Chapter 3 comprised of a cross-sectional observational study that aimed to assess the relationships between VG duration and various HRCoF within adolescents and predict each HRCoF against weekly VG time. This study included 180 adolescents aged 12.89 $\pm$ 1.43 years old. Weekly VG duration and physical activity (PA) habits were reported through questionnaire; and flexibility, balance, handgrip strength, jump height, coordination and reaction time were measured. Generalised additive modelling was used to assess the relationships between VG duration and these HRCoF. VG was associated with faster reaction times, however, was negatively associated with flexibility, balance, handgrip strength, jump height and coordination. Balance, jump height and coordination had relationship changes at 32.86, 28.04, and 41.31 h/week, respectively. Sex and age were positive predictors across these six HRCoF. Overall,

this highlights the agreement with current research literature of VG positively influencing reaction time, however, this thesis goes further to show that extended durations of VG is negative associated with all other HRCoF measured within this thesis in adolescents. Therefore, this can inform parents, educators and policy makers to encourage a balance between VG participation and PA, especially within adolescents. This is the first study to identify these relationships within adolescents. Future research should prioritise longitudinal and intervention studies to identify causal effects between VG and HRCoF.

Chapter 1: Introduction

1.1 Background

1.1.1 A Brief History of Video Gaming

Video gaming (VG) is one of the most popular hobbies/past-times across the globe. Its roots date back to the invention of computers and has, and continues, to significantly grow with large global revenue streams (1,2). The early origins of VG devices began in 1947 with the first known interactive electronic game 'Cathode Ray Tube Amusement Device' resembling a missile simulator. The 1950s and 60s saw 'OXO (Noughts and Crosses)' a simple graphical tic-tac-toe game developed by A.S. Douglas in 1952, 'Tennis for Two' created by W. Higinbotham in 1958, and 'Spacewar!' the first widely distributed digital computer game developed by S. Russell in 1962.

The 1970s saw the emergence of the arcade era with 'Computer Space', the first commercially available video arcade game in 1971, although this release was not successful as it was too complex for most players. In 1972, 'Pong' was released by the global giant Atari as the first commercially successful video game which sparked the arcade game boom with 35,000 units sold, and 'Magnavox Odyssey', the first home gaming console that used plastic overlays on TV screens, though with no sound or graphics at the time, which sold 350,000 units before it was discontinued in 1975. Atari released a home console version of 'Pong' in 1975, selling 150,000 units during its first holiday season. The late 1970s saw the introduction of home consoles, the Atari 2600 was released in 1977 and was the first console for home use with interchangeable cartridges, with over 30 million units sold worldwide, making it a game-changing revolutionary innovation in getting consoles into homes.

The 1980s saw growth to arcade gaming with Pac-Man in 1980 and Donkey Kong in 1981, and massive growth to home console gaming with Nintendo releasing the Nintendo Entertainment System in 1983 in Japan, and in 1986-87 worldwide, and launching major game franchises, for example ‘Super Mario Bros.’ and ‘The Legend of Zelda’. In 1988, one of the gaming industries major rivalries was started between Nintendo and Sega, with Sega releasing the Sega Genesis and later released ‘Sonic the Hedgehog’ in 1991 which boosted Sega Genesis dramatically. The current landscape of VG appeared with the internet, with many stakeholders emerging in the late 1990s and early 2000s, for example Sony Interactive Entertainment with PlayStation and Microsoft with Xbox, respectively, creating another of the VG industries major rivalries (1).

1.1.2 Contemporary Video Gaming

There are various ways to engage in VG, for example more traditional sedentary VG such as sitting and playing on a keyboard, controller or joystick, or more recently active video gaming (active-VG) such as virtual reality (VR) and exergaming. VR is technology that allows the player to immerse themselves in a simulated 3D environment, these are typically wearable headsets, while active-VG is VG that involves some kind of physical activity (PA). In some cases, active-VG can be fused with VR to create a completely immersive gaming experience for the user. Additionally, portable handheld devices such as the PlayStation PSP and the newer Nintendo Switch, are very popular devices for VG on the go. Newer next-generation consoles such as the Sony PlayStation, Nintendo systems, Microsoft Xbox, and the hybrid Steam console, are now powerful enough to provide sedentary VG and active-VG across thousands of Triple A game titles with realistic graphics providing users easy access to engage with VG and endless entertainment. Triple A games are those which are high-budget, blockbuster titles developed by large studios, featuring top-tier graphics, extensive marketing, and polished gameplay, e.g., ‘Red Dead Redemption 2’ and ‘Grand Theft Auto V’. Additionally, the custom personal computer gaming space has increased in popularity with the ability of owning a gaming library with massive Triple A titles through places such as Steam, EA, Epic games etc.

There are many ways to play video games, with various play styles, whether it is gaming single player, multiplayer, or online with friends or strangers, it has been designed for anyone to play. In addition to being able to play VG in many ways, there is a vast variety of different game genres to choose from; action and adventure (e.g., ‘Assassin’s Creed’), first person shooter (FPS) (e.g., ‘Call of Duty’), multiplayer online battle arena (MOBA) (e.g., ‘Fortnite’), sports (e.g., ‘NBA 2k26’), role playing (e.g., ‘The Sims’), platformer (e.g., ‘Super Mario’), survival (e.g.,‘Minecraft’), racing (e.g., ‘F1’), and fighting (e.g., ‘Mortal Combat’), it is truly endless.

VG can be played recreationally at multiple difficulty levels as well as professionally, known as electronic sports (Esports) where athletes train and compete as their job, similar to a traditional athlete, with competition cash prizes up into the millions (3). For example, the Fortnite World Cup Solo Finals in 2019 had a cash prize of $3 million. Some video gaming players (VGP) broadcast (known as streaming) themselves live to online audiences through platforms such as Twitch, YouTube and Kick playing video games and Esport athletes (E-athletes) sometimes broadcast themselves training as well. Some VGP become so successful in VG streaming that it becomes their job that they get paid to do through contracts with the streaming platforms, subscriptions, advertisement revenue, and donations. Within this thesis ‘E-athletes’ refers to individuals who compete at VG tournaments, ‘habitual-VGP’ refers to individuals who play video games for their own enjoyment as a hobby that do not compete, and ‘VGP’ refers to both E-athletes and habitual-VGP. Additionally, spectatorship of Esport competitions and events are popular, for example the 2024 world championship of ‘League of Legends’ reached a peak of 6.85 million viewers worldwide, this is reported to be the highest viewed Esport competition (4).

1.1.3 Popularity of Video Gaming

The popularity of VG can been seen through this rapidly developing industry and technology, making the VG space a multi-billion-dollar industry, allowing any user the ability and accessibility to pick up a controller and play from anywhere in the world. The leading provider of global VG market intelligence, Newzoo, has reported a total global revenue increase from $91.1 billion to $177.9 billion in the past decade within the VG industry, and has estimated a growth of $200 billion by 2027 (5). In 2025 EA Sports, known for ‘EA Sports FC’ (formerly FIFA) and ‘The Sims’, was sold for $55 billion, which puts into context the money and popularity within the industry. Game franchises are also being created into films and series, for example Lara Croft in 2001 and 2003 which grossed $274.7 million and $160.1 million respectively, and more recently Minecraft in 2025 which grossed over $955 million and Super Mario in 2023 which grossed $1.36 billion worldwide. Netflix has also created a series ‘Arcane’ which is based on ‘League of Legends’, which has two seasons and has won an Emmy for Outstanding Animated Program for both seasons, these are only a few examples. This shows how popular and influential the VG industry is and how it is continuously expanding.

Additionally, since the COVID-19 worldwide pandemic in 2020, there has been a sharp increase in popularity of VG, as people were confined to their homes during lockdowns and social isolations (6,7). 2020 saw a peak of 2.7 billion VGP and the streaming platform Twitch, saw a one-third increase in viewership in March 2020 alone (6). VG provided digital communication, entertainment, and a safe social alternative, causing a peak in interest and engagement for all ages (6,7). The popularity of VG has increased across sexes and ages from 2015 (44% males, 39% females, 66% 16-24 year-olds, 63% 25-34 year-olds, 44% 35-44 year-olds, 42% 45-54 year-olds, 25% 55-64 year olds, and 0% 65+ year-olds) to 2024 (57% males, 50% females, 85% 16-24 year-olds, 71% 25-34 year-olds, 63% 35-44 year-olds, 58% 45-54 year-olds, 41% 55-64 year olds, and 25% 65+ year-olds) within the United Kingdom (8). This increase has also been seen in Twitch spectatorship increasing from an average of 539,000 spectators in 2015, to an average of 2.17 million in 2025 (9). Therefore, with these and future increases in VG popularity, engagement, and advancements in technology, there is a necessary demand to explore the associated range of physical health implications of VG.

It is important to note that sedentary behaviour is defined as any waking behaviour characterised by an energy expenditure $\leq$1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture (10). Sedentary behaviour and lack of PA has been linked to various negative health implications, for example, increased risk of all-cause and cardiovascular mortality, cardiovascular disease, type 2 diabetes mellitus, metabolic syndrome, obesity, high blood pressure, and musculoskeletal disorders (11-14). The majority of current literature focuses on E-athletes, whereas this thesis is focussed on habitual-VGP, however it is necessary to include E-athletes due to extremes making for useful comparisons. With many VG experiences being sedentary in nature, there is reason to expect that VG may relate to health and health-related components of fitness (HRCoF). The next sections focus on these links.

1.2 Health and Video Gaming

1.2.1 Body Composition and Physical Activity Levels

Low PA levels and high body fat percentages (BF%) found within VGP bring concern to their physical health (15-17). DiFrancisco-Donoghue et al. (16) found within 13 collegiate E-athletes, aged 18 to 25 years old, when compared to 11 age-matched non E-athletes, that PA levels were significantly lower (1.7 vs. 4.8 days per week, respectively) and BF% were significantly higher (24 vs. 19.1%, respectively). Although, body mass index (BMI) was found to be similar, 23.7 vs. 24.9 kg/m^2, respectively (16). These E-athletes additionally had lower lean body mass and bone mineral content, portraying a poor body composition with increased risk of potential health complications and injury (16).

BMI has been found to increase as VG time increases and has a significant inverse relationship to PA, especially within obese E-athletes with prolonged sedentary time (15,17,18). Differences in PA levels have been found between male and female E-athletes, males reported higher PA levels which could be attributed to the influence of biological and social factors (17). Basoglu identified within 115 male and 21 female E-athletes, males total MET-minutes per week were greater than females, 4813.9 vs. 3435.0, respectively (17). Additionally, DiFrancisco-Donoghue et al. (19) found that 40% of 65 E-athletes aged 18-22 years old, do not partake in any PA.

This is not exclusive to E-athletes, these trends are also found within habitual-VGP (20). Research has shown that habitual-VGP are more commonly within the lower quartiles of weekly PA, indicating an increased risk to chronic physical health conditions (20). These findings of decreased PA, increased BMI and sedentary time within VGP present the potential negative implications of prolonged VG upon physical health (15,16,20). Due to this increased sedentary time, VGP often report musculoskeletal and ocular side effects.

1.2.2 Musculoskeletal and Eye Pain

Prolonged VG time has been linked to increased musculoskeletal pain in various populations, bringing to light the long-term consequences upon health (21). A variety of musculoskeletal issues have been found within VG populations, especially within E-athletes (19). Within 65 collegiate E-athletes, aged 18 to 22 years old, who trained between 3 and 10 hours per day, the most commonly reported complaints were back and neck pain (42%), wrist pain (36%) and hand pain (32%) (19). Due to the repetitive movements of VG, E-athletes who train up to and more than 10 hours per day, have the potential for overuse injuries to their upper limb attributed to using over 400 fine motor actions per minute when VG (22,23). Unfortunately some of these injuries, such as carpel tunnel syndrome and tendinopathies, can be prematurely career ending for E-athletes (23).

Back and neck pain have been attributed to postural issues in VGP during VG, particularly in the scapular and lumbar areas (24,25). Research has found that within collegiate E-athletes, 35% report back or neck pain while VG and bad posture (26). Within 30 minutes of VG, a forward displacement of the head to the spine can occur stressing the cervicothoracic junction and paraspinal muscles when maintained for prolonged periods of VG time (26). Additionally, an increase of 10 pounds of force torque upon the cervical extensors happens with each inch the head displaces forwards, while also adding stress upon the lower back intervertebral discs, which can potentially cause herniations (26). Furthermore, one study has found, within 10 male E-athletes aged 21.9 $\pm$ 1.19 years old, a significant decrease in thickness to the trunk stabiliser muscle complex compared to 10 age-matched control participants (25). For example, the right and left transverse abdominals thickness were significantly decreased within the E-athletes to the control group, 0.27 cm to 0.37 cm respectively, which for the E-athletes resembles that in older adults with chronic lower back pain (25). However, this research has only been conducted with E-athletes, meaning that these findings have not been corroborated within habitual-VGP.

Additionally, these implications upon health could have been exasperated during and after the COVID-19 pandemic when VG increased in popularity and time spent VG soared due to pandemic lockdowns and social distancing (27). This increase in screen time and sedentary behaviour has the potential to cause VGP to be at a higher risk for adverse effects upon their physical health than before the COVID-19 pandemic (27).

In addition to musculoskeletal pain, eye pain and fatigue is another complaint commonly reported among VGP (19). This was reported as the most common complaint within 65 E-athletes, aged 18 to 22 years old, with at least 56% of individuals reporting eye fatigue (19). This is occasionally partnered with other ocular symptoms including eye strain and dry eyes (15). With more than 35% of collegiate E-athletes training more than five hours per day with typically more than two hours before a break, the prolonged screen time can lead to computer vision syndrome (26). This can materialise in blurry vision and tension headaches, which is prevalent in approximately 90% of individuals who fix their eyes on computers for more than three hours per day (26). Furthermore, in pixelated images, there can be a lack of contrast and definition which puts strain on the oculomotor system, due to an increase in saccadic movements and convergence, and decrease in blink rate (26). Interventions to reduce VGP digital eye pain and fatigue complaints needs to be assessed by professionals to mitigate these symptoms and improve VG performance (28). However, this research only included E-athletes, therefore demonstrating a lack of research involving habitual-VGP. Although sedentary VG can have negative implications upon physical health, active-VG can be beneficial.

1.2.3 Active Video Games

Active-VG can be valuable, especially within children and adolescent populations suffering with overweight and obesity (29,30). Active-VG can significantly increase energy expenditure when used alongside multi-component exercise within these populations (29). Research has seen energy expenditure increase to 5.68 kcal/min and 4.66 kcal/min in 26 boys and 19 girls respectively aged 9 to 12 years old with overweight and obesity, which shows this can be an effective strategy for this population to improve their physical health (29). Active-VG also creates a greater energy expenditure than sedentary VG within adult populations, with intensities comparable to walking speeds over 3.5 mph (31). One study found that within 15 hypertensive participants aged 49 $\pm$ 1.6 years old, systolic and diastolic blood pressure decreased with active-VG, -14.4 $\pm$ 3.0 mmHg and -7.6 $\pm$ 1.5 mmHg respectively, showing that active-VG can be beneficial to a wide range of populations (32).

Additionally, active-VG has also been proven to be beneficial for traditional athletes looking for alternative exercises in their training (33). Cakir-Atabek et al. (33) found within 22 male athletes, aged 20.6 $\pm$ 2.2 years old, dancing and fighting active-VG had moderate and high intensities of MET 7 and MET 9 respectively, which were found to be as effective as brisk walking and running. This training can be particularly effective due to its enjoyability and ability to reduce monotonous traditional exercises and training (33). Additionally, whole-body isometric active-VG has seen to result in an increased energy expenditure with participants reporting no increase in perceived exertion (34).

However, active-VG have been reported as less enjoyable compared to sedentary VG, with interest in active-VG being low, there can be no guarantee for them to be completely effective for weight reduction as they may be played less over time (30,35). Moreover, even though active-VG elicits greater intensities than sedentary VG, it does not compare to intensities elicited by traditional sports performance (36). Scanlan et al. (36) found within 10 males, aged 20.2 $\pm$ 0.4 years old, that tennis game-play caused an increased heart rate (67 $\pm$ 5% HR_{max}) and METs (5 $\pm$ 0.2), compared to active-VG (45 $\pm$ 2% HR_{max} and 1.1 $\pm$ 0.1 METs, respectively), and therefore, should not be recommended as an alternative for traditional sports participation. Though, they can be used to reduce sedentary behaviour, less active but greater enjoyable active-VG could be a promising method for this (35). Therefore there are positives of active-VG though negatives of sedentary VG upon health, additionally there are numerous topics vastly covered within current literature which warrant noting, though do not directly link to this thesis' topic.

1.2.4 Areas of Current Extensive Research

There are various areas of current literature which have been extensively researched, these are nutrition, sleep, mental health and medical practices. VGP nutritional habits have been identified as poor, hence potentially leading to negative health outcomes, specifically within the adolescent population (37,38). Studies have reported that habitual-VGP who game more than three hours per day are 24.1% more likely than non-VGP to have lower rates of physiological HRCoF, poorer dietary habits, such as less fruits and vegetables and more sweetened soft drinks leading to higher rates of obesity (37,38). Additionally, food intake has seen to increase with a single session of VG whether participants reported feeling hungry or not, with an energy surplus of 682kJ (38). This suggests that prolonged habitual-VG could contribute to worse nutrition choices. This energy surplus and increase of sweetened soft drinks can lead to poor sleep habits.

VG influence on sleep has been greatly researched and has been found to be detrimental to sleep. Sleep quality, duration, latency, and daytime sleepiness have been seen to be negatively affected by VG within E-athletes and habitual-VGP ranging from adolescents and adults (15,26,39,40). This is likely due to computer monitors using blue spectrum light-emitting diodes (400-900nm), which increases alertness and thought processing (26). This is attributed to the pineal gland reducing the secretion of melatonin, caused by blue light stimulating retinal ganglion cells in the eye, which disrupts the body's circadian rhythm making it harder to fall asleep (26).

In addition to the negative impact VG can have upon physical health, it important to note the impact upon mental health. VG can negatively affect mental health in various ways, particularly increasing stress levels and depression rates within E-athletes, due to performance pressures during team and individual competitions (41,42). This increased stress has been highly linked to burnout and social phobia anxiety, which all significantly predicted ill mental health (43). Mental health issues are not confined to E-athletes, adult and adolescent habitual-VGP have been reported to suffer depression and anxiety symptoms (41,44,45). However, VG has been found advantageous within college students to form friendships, reduce negative peer pressure, and improve grades (46).

Furthermore, VG has slowly been introduced into healthcare since the early 1990s (47). VG has had positive outcomes across a wide variety of conditions, for example, rehabilitations, Parkinson’s disease, multiple sclerosis, and cerebral palsy (48-54). VR therapy addressing freezing gait, impaired balance, and cognitive function within Parkinson’s disease patients has been significantly effective (49). Additionally, a VR rehabilitation programme addressing reaction time within children with cerebral palsy has been significantly effective, increasing their reaction times by 43% (51). Moreover, technologies surrounding VG, such as gamified VR, are being integrated into medical practices and workflows to improve patient experience and outcomes (55). Another use of VG within medical practices is training surgeons, especially in laparoscopic skills (56-59). Therefore, the research within nutrition, sleep, mental health, and medicine have been studied extensively and continue to grow and integrate into society. However, these are not the main focus for this research project.

1.3 Video Gaming Performance

Although VG is associated with negative physical health with low PA levels being seen within VGP (16,17), research has shown that PA has the potential to enhance VG performance, specifically within E-athletes. High-intensity interval training has been found to significantly enhance gaming outcomes among E-athletes, increasing their chances of winning (60). Similarly, greater VG performance has been linked to short bouts of cardiovascular PA prior to VG (61). For example, 20 ‘League of Legends’ players aged 22 $\pm$ 3.0 years old, displayed significantly increased target elimination capacity of 111.38 to 121.17 when resting before VG compared to participating in PA before VG, respectively (62). Additionally, accuracy after PA compared to rest prior to VG significantly increased, along with a 17% improvement in positive affect, signifying benefits which could support performance (62).

Rather than PA directly prior to VG, general physiological HRCoF have been found to be beneficial to VG performance. Dykstra et al. (63) found within 27 male E-athletes, aged 21.2 + 3.3 years old, a significant negative correlation between VO_{2max} and reaction time (RT) ($r = -0.338$, $p = 0.043$), meaning that an increased cardiorespiratory fitness is related to a decrease in reaction time and greater efficiency, suggesting an improvement in VG performance. This suggests that someone's physiological HRCoF could optimise mental alertness and precision in high-stakes VG. However, the research evidence for this is somewhat limited and this needs to be explored within other video games and genres (62). Additionally, this research is focussed solely on E-athletes, excluding habitual-VGP, which could be due to the high performance requirement of E-sports and the large cash prises at E-sport tournaments as previously mentioned in 1.1.2.

PA is associated with cognitive benefits which it seems to be plausible to suggest to be the central mechanism behind these VG performance improvements. Increased blood flow and oxygenation to the brain could be one reason of enhanced cognitive ability, such as attention, information processing, and memory that transitions into VG process and success (64,65). These functions are specifically critical in fast-paced game play which require fast decision making and multitasking. In addition, game-related PA, instead of traditional PA, have also shown to boost VGP skills and are increasingly being used by Esport coaches, particularly when they mirror the cognitive demands of the specific video games the E-athletes are training in (66). However, the research pertaining to the relationship between PA and VG performance isn't universally cohesive. While some studies show improvements in cognitive function and processing speeds following PA and breaking up prolonged sitting during VG sessions (67), some studies provide no evidence that PA prior to VG improves performance, despite the physical health improvements (68). These inconsistent findings within the research show the intricateness of incorporating PA routines into E-athletes training programmes and suggest that many factors of PA, such as type and duration, all play a critical role in determining its impact on VG performance (66,68). Therefore, PA can potentially be beneficial to VG performance, though should not be the sole way to enhance performance. With all the negative associations with health and this potential way to benefit VG performance, it is important to understand the physiological demands VG has upon the body.

1.4 Acute Physiological Demands of Video Gaming

Within research, Esports has continuously shown to elicit acute physiological responses that challenge the idea that traditional sedentary VG is a passive activity (69-72,). The current literature portrays that E-athletes, specifically those that play FPS games, encounter significant increases in sympathetic nervous system activation (69). Sousa et al. (69) analysed physiological data, pre- and post- a 2.5h VG session, from 17 male E-athletes aged 18-30 years old and found a significantly larger increase in heart rate and systolic blood pressure, 6 bpm and 9 mmHg respectively, within FPS than MOBA E-athletes, suggesting that FPS games can cause a greater response of the sympathetic nervous system. This has been corroborated by other researchers finding an increased cardiovascular stress response and systolic blood pressure within more aggressive or violent video games (70,73,74). These responses to more aggressive video games are likely due to catecholamines, epinephrine and norepinephrine, being secreted by the adrenal glands causing an increase in heart rate and blood pressure, respectively (69). More commonly known as the ‘fight or flight’ response, this in turn can cause enhanced alertness and motor precision. However, if this sympathetic nervous response increases too greatly, it can cause impaired decision making leading to an increase in errors made and potentially causing a loss over a win during VG. Therefore, VG cannot be seen as physiologically passive, though involves minimal movement, and hence it is important to view VG as a sport, to treat E-athletes and habitual-VGP as such and assess their physiological and psychological adaptations to this sport.

Additionally, increases in respiratory rate and minute ventilation, further call attention to the physiological “toll” of Esports (70). 17 male E-athletes aged 18-30 years old wore smart shirts, containing electrodes capable of measuring common physiological parameters, during a VG session up to 2.5h (70). Respiratory rate and minute ventilation were significantly greater within the winning team than the losing team during the VG session, with 20 breaths/min and 10267 ml/min compared to 18.5 breaths/min and 7473 ml/min, respectively (70). This could be attributed to the winning team having a greater cognitive load and level of concentration, due to the widely accepted evidence that high cognitive activity triggers a sympathetic response causing an increase in these physiological parameters (70,75,76). This implies a connection between video game play intensity and internal stress responses (70). This increased respiratory demand, has similarly been observed along with increased energy expenditure (71). Nicholson et al. (71) found, within 13 male E-athletes aged 20.7 $\pm$ 2.67 years old, significantly increased median energy expenditure (1.2 to 1.45 kcal/min), oxygen consumption (0.27 to 0.29 L/min) and carbon dioxide production (0.20 to 0.27 L/min) from resting conditions to Esport gameplay. This increase in energy expenditure can be partly explained by Kocak et al. (77) illustrating a strong significant positive correlation between actions per minute and MET’s ($r = 0.818$, $p = 0.002$). Therefore, these findings further demonstrate the elaborate cardiorespiratory and metabolic demands during VG. However, these acute physiological demands have not been corroborated within habitual-VGP, although it can be hypothesised that the demands are similar since they are playing the same games, though at different skill levels.

Neuropsychological data was also analysed by Sousa et al. (69) to assess executive function within these 17 E-athletes, faster reaction times were exhibited although partnered with decreased accuracy and increased impulsivity. Alternatively, problem solving saw no decrement in performance (69). Similarly, a decrease in inhibitory control has been observed within FPS VGP, while having faster reaction times (78). However, the link connecting VG and cognitive ability is complex. While some research shows that long-term VGP have improved adaptations to cognitive function due to biopsychosocial factors (79), other research similarly shows possible cognitive trade-offs (80). Kowal et al. (80) found 102 action genre VGP, aged 18 to 45 years old, had faster RT on cognitive tests compared to non-VGP, such as the Stroop (910 $\pm$ 203 ms to 110 $\pm$ 260 ms, respectively) and Trail-Making (37.3 $\pm$ 8.55 s to 43.19 $\pm$ 9.79 s, respectively) tests, though action genre VGP made more errors, suggesting a favouritism of speed over accuracy with long-term engagement in VG. This has been further corroborated by other research pinpointing the faster RT but reduction in inhibition processes and accuracy (81). These findings point to a complex psychophysiological state during VG, where during stress, elevated cognitive demands can compromise fine motor precision, which could in turn cause an individual to lose at a game instead of win. However, it’s is important to note that the majority of these findings regarding VGP acute physiological demands have focussed on E-athletes with very limited research on habitual-VGP. Furthermore, these cognitive trade-offs appear to be a learned adaptation of prolonged engagement in VG, which calls to question what other adaptations can occur, physically and mentally, with continued exposure to VG?

Although E-athletes exhibit these physiological demands of high-stakes VG, they continue to have exceptional cognitive HRCoF, for example visual-motor coordination, through faster saccadic reaction times and peak velocities (72). Traditional frameworks of HRCoF do not include cognitive components of fitness due to them being defined as skill-based components of fitness (82), however coordination and reaction time have been strongly associated with executive function and processing speeds (83,84). Therefore, this study defines HRCoF as the physiological and cognitive attributes of fitness that are associated with physical health, functional ability, and cognitive performance. The impact of the psychophysiological state during VG on long-term adaptations to physiological and cognitive HRCoF is important to understand, due to various HRCoF being associated with improved physical and cognitive health (83-91). Greater cardiorespiratory fitness and muscular strength have been associated with lower all-cause and cancer mortality, risk of stroke and metabolic syndrome (85-89). Improved flexibility and balance have been associated with improved mobility and reduced injury risk (90,91). Therefore, the physiological and cognitive HRCoF levels of VGP is important to explore, due to the impact HRCoF has upon health.

1.5 Health-Related Components of Fitness and Video Gaming

E-athletes' physiological HRCoF have been found to have nuanced findings (92). One study found within 196 male E-athletes, aged 20.5 $\pm$ 2.4 years old, cardiorespiratory fitness was characterised as average, 41.92 $\pm$ 5.41 ml/kg/min, and muscle power generated at VO_{2max} was lower than age-matched physically active men, 210.29 $\pm$

42.63 W (92). This could be attributed to sedentary VG not eliciting the same physiological demands as PA which are necessary for physiological adaptations over time that cause an increase in cardiorespiratory fitness and muscle power. For example, other elite athletes, such as footballers, have high VO_{2max} scores, 61.37 $\pm$ 5.07 ml/kg/min (93), and high muscle power in squat jumps and countermovement jumps, 845.04 $\pm$ 1.48 and 844.25 $\pm$ 1.48 W, respectively (94). Cardiorespiratory fitness increases due to adaptations of increases in cardiac output, oxygen transport and diffusion capacity due to the left ventricle enlarging and being eccentrically hypertrophied, increase in plasma volume within the blood stream and capillaries surrounding muscle fibres, over prolonged PA (95,96). Muscular power increases due to adaptations of increases in motor unit firing frequency and synchronisation and greater force production capacity, due to increased motor unit recruitment, muscle hypertrophy, especially type II fibres, and improved fatigue resistance of fast fibres from enhanced type IIa fibre oxidative capacity, over prolonged PA (97,98). As a result, this cannot occur during sedentary VG and hence these elite E-athletes have lower cardiorespiratory fitness and muscular power levels than other elite athletes and age-matched physically active men, though is still considered as average (92).

This study also characterised handgrip strength as average or above in the left and right hand for 62.86% and 67.14% of 18-19 years olds, and 65.94% and 75.82% of 20-24 year olds, respectively (92). This could be attributed to the repetitive use of the hands using a controller or keyboard and mouse during VG with the use of over 400 fine motor actions per minute (23). This could lead to hypertrophy within the hands due to increases in muscle protein synthesis causing a rebuilding of a stronger cross-sectional area with improved fibre packing, increased growth capacity and fibre enlargement, causing this average or above grip strength (99,100). Therefore, with E-athletes cardiorespiratory fitness and muscular power categorised as average and handgrip strength as average or above, Klimek et al. (92) considered E-athletes to be overall physically fit. However, this study did not include females or habitual VGP, and had a limited number of fitness tests, meaning a broader variety of fitness tests is needed to obtain a full view of fitness within VGP in future research (92).

While physiological HRCoF are under researched, cognitive HRCoF have been found to be benefitted by VG. Sampalo et al. (101) found through a systematic review of 13 studies, that action genre VG is significantly associated with faster reaction time and processing speeds within young adult habitual-VGP. Luu et al. (102) found that E-athletes (n = 12), aged 18 to 22 years old, had significantly faster reaction times than non E-athletes (n = 12), in the colour cue test (269.83 ± 23.46 ms to 290.83 ± 36.50 ms, respectively) and the ruler drop test (174.58 ± 26.14 ms to 223.47 ± 31.11 ms, respectively). Ersin et al. (103) found a dose response of VG to improved visual and aim reaction time, E-athletes who played more than 14 hours per week had significantly faster visual (227.13 ± 33.15 ms) and aim (440.61 ± 64.93 ms) reaction time than those of E-athletes who played less than 14 hours per week (278.67 ± 45.44 ms and 578.83 ± 123.98 ms, respectively). Additionally, it is beneficial to understand both general trends, such as Luu et al. (102) and weekly VG duration comparisons, such as Ersin et al. (103), however threshold analysis would provide for greater interpretations. Therefore, this means that engaging in VG may significantly enhance an individuals reaction time, adding to the evidence that VGP HRCoF levels are adequate or greater.

Many other cognitive benefits of VG have been found over the past decade, especially in action genre VG (28,104). An improvement in visual cognitive skills, for example, visual attention and perception is seen in action genre VGP (28). These cognitive benefits could be due to the high demands to track various dynamic visual stimuli and respond to these, which could be attributed to an increase in brain region engagement (28,105). Research has also found that action genre VGP have increased attention capacity due to the constant need to have their concentration on multiple stimulus at once, meaning they are able to focus on a primary and secondary task without compromising performance on either task (104).

It has also been reported that enhancements in multitasking, critical thinking, and collaborative abilities have been found in those that engage in VG (106). Particularly, specific in-game experiences in non-battle scenarios, can lead to increased visual attention and both explicit and implicit memory, which positively improves behavioural intentions (101,107). Moreover, these trends in increased cognitive ability are seen in adolescent habitual-VGP as well, with increased active memory and improved reasoning skills, compared to non habitual-VGP in the same population (108). These cognitive benefits could be attributed to neurobiological structural changes from VG (109,110). Structural brain properties can be influenced by core elements of VG, for example spatial navigation and visuomotor coordination, with impacts persisting longer-term than short-term intensive VG (109). Research has also examined the differences in neural adaptations between different VG genres, for example FPS habitual-VGP exhibited greater performance in attention control and sensorimotor processing tasks compared to MOBA habitual-VGP (110). This could be attributed to an increase in grey matter volume or deformation to the sensorimotor regions and visual cortex within FPS habitual-VGP compared to MOBA habitual-VGP (110). Therefore, VG can be beneficial for cognitive HRCoF and various cognitive abilities.

1.6 Thesis Aims

Overall, VG research has covered a wide variety of topics, for example musculoskeletal and eye pain (19,21-28), active-VG (29-35), and the acute physiological demands of VG (69,70,73-75,77-79). VG can have various negative implications upon health, for example increased BMI, back pain, and ocular fatigue, however active-VG can be beneficial to health (19,21-35). PA has been associated with greater VG performance and the acute demands of VG, for example, increases in the sympathetic nervous system, respiratory rate and minute ventilation, do not inhibit cognitive ability while playing VG (60-61,69,70,73-75,77-79). However, the most under researched topic within this area is the HRCoF of VGP, and the long-term physiological adaptations to those that engage in VG.

There is a paucity of evidence relating VG to physiological and cognitive HRCoF in habitual VGP. Therefore, the main aim of this research project is to investigate the relationship between VG and physiological and cognitive HRCoF. Chapter 2 aims to collate and synthesise the current literature on the implications of VG across HRCoF within both E-athletes and habitual-VGP. Chapter 3 aims to assess the relationships between VG duration and various cognitive and physiological HRCoF within adolescents using generalised additive modelling to smooth these relationship; to then predict each HRCoF against weekly VG time in adolescents..

Chapter 2: A Systematic Review of Video Gaming and Health-Related Components of Fitness

2.1 Introduction

Video gaming (VG) is interactive electronic entertainment, where players use input devices to control on-screen characters or actions, receiving visual and auditory feedback on a display for example, a TV or computer monitor. VG has become one of the world's most popular leisure activities, which is seen through the increase of the streaming platform Twitch's average and peak concurrent spectators over the past decade, from 539,000 average and 2.1 million peak viewers in 2015 to 2.17 million average and 14 million peak viewers in 2025 (9). In 2023, the UK Government released key VG demographic statistics, with 60% of adults and 91% of children and adolescents engaging in VG (111). With this drastic increase in VG uptake, there has been an associated increase in sedentary behaviours and a decrease in physical activity (PA) (15-20). It is well documented that these behaviours are linked to conditions such as diabetes mellitus, obesity, cardiovascular disease and all-cause mortality (10-14). Therefore, those that regularly engage in VG are of an increasing concern.

As mentioned in Chapter 1, ongoing evidence into VG participation has been linked with various physical health issues. For example, musculoskeletal pain and vision problems, which are mainly attributed to long durations of static poor posture, and prolonged screen time (19,22,23-26,28,112,113). Additionally, weight gain is associated with increases, by 5% and above, to body mass index (BMI), waist circumference and body fat percentages (BF%), which are significantly correlated with the amount of VG played per hour (15,16,18,114). Moreover, VG induces sedentary behaviours which appears to play a major role within these findings, obese habitual-VG players (VGP) had significantly lower PA and greater sedentary behaviour levels than their peers, showing a direct inverse relationship (17).

PA plays a major role in reducing sedentary behaviours, in order to improve health, hence the current literature covers VGP (encompassing both E-athletes and habitual VGP; see Chapter 1 page 12) PA levels (17,115). Evidence indicates that PA levels amongst VGP are frequently low, with 39.1% reporting engaging in PA, with various studies reporting higher levels of sedentary behaviour and failure to meet recommended PA guidelines (15,16,19,92,116,117). Conversely, several studies have demonstrated that those who do engage in VG can still participate in high levels of PA, with 87.1% of VGP reporting to meet the World Health Organisation recommendations for PA of 150 minutes of moderate intensity exercise or 75 minutes of vigorous intensity exercise exercise per week (118-122). This vast difference in PA levels across VGP could be due to the range of continents where these studies have been based, for example, Australia (15,117), Asia (116), North America (16,19), South America (119), and Europe (118,120,121). Additionally, these studies ranged from 2019 to 2024, which could cause discrepancies between findings. Therefore, these findings pertaining to VGP PA levels are inconclusive.

PA can improve various health-related components of fitness (HRCoF) including cardiovascular endurance, muscular strength, balance, flexibility, reaction time (RT) and coordination (123-126), which are in turn associated with positive physical and mental health (127-134). Hence, these inconclusive PA levels found within VGP have sparked research objectively evaluating their HRCoF levels (80,92,101). Adult male electronic sport athletes (E-athletes) maximal oxygen consumption has been characterised as average, 41.92 ± 5.41 ml/kg/min, muscle power lower than age-matched physically active males, 210.29 ± 42.63 W, and handgrip strength as average or above for the left and right hand within 62.86% to 75.82% of 18-24 year olds (92). Additionally, engagement with VG is associated with improvements of up to 21.8% in reaction time, which could be due to enhanced processing speeds, and sustained and divided attention (80,101,102). Conversely, those that play action-based VG have shown to adopt strategies that favour speed over accuracy, particularly in inhibitory control assessment tasks (80). Collectively, these findings highlight potential differences in the relationships between physiological and cognitive HRCoF and sedentary VG. Therefore, this shows that the current evidence evaluating VGP HRCoF levels remains inconclusive, underscoring the need for comprehensive synthesis. However, to the authors knowledge, no literature review has collated these findings, highlighting the necessity for a systematic review to advance understanding in this area. Such an approach will delineate the extent and strength of the existing evidence base, organise findings into coherent and meaningful interpretations, and identify precise gaps within the literature that warrant further investigation.

As discussed there is comprehensive literature regarding musculoskeletal issues, body composition, and ranging PA levels within adult VGP, and in summary there is agreement that VG can affect health in many aspects. However, at the current time there has been no systematic literature review that explores the topic of HRCoF levels, physiological or cognitive, within VGP of any age. This will not include intervention studies due to these studies identifying the causality of VG, not the relationships between VGP and their HRCoF. Therefore, the aim of this review is to collate and synthesise the current literature on the implications of VG across HRCoF within both E-athletes and habitual-VGP.

2.2 Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guidelines (135).

2.2.1 Search Strategies

A comprehensive literature search was conducted to identify applicable research studies. The following database searches were conducted on 11th February 2025 using three databases: EBSCOHost, Sport Discus, and Scopus. The following keywords were used in various logical combinations and mesh terms:

(“Video gaming” OR “video games” OR “gaming” OR “esports” OR “console gaming” OR “PC gaming” OR “personal computer gaming” OR “Xbox” OR “PlayStation” OR “VR” OR “virtual reality” OR “Nintendo” OR “Wii”) AND (“components of fitness” OR “fitness components” OR “health-related fitness” OR “exercise health” OR “handgrip strength” OR “strength” OR “handgrip dynamometer” OR “1 rep max” OR “1RM” OR “one repetition maximum” OR “hypertrophy” OR “atrophy” OR “balance” OR “reaction time” OR “reaction speed” OR “coordination” OR “peak power output” OR “anaerobic power” OR “explosive power” OR “jump height” OR “hamstring flexibility” OR “lower back flexibility” OR “cardiovascular endurance” OR “cardiovascular fitness” OR “VO2max” OR “VO2peak” OR “aerobic endurance” OR “aerobic capacity” OR “anaerobic capacity”).

The following filters were applied in each database: 1) written in English, 2) full text only, 3) published in a journal, and 4) human participants. The final search results were sorted and exported into reference management software Rayyan® (Rayyan Systems Inc., Cambridge, MA) for deduplication. Duplicates were also manually inspected by one author (BT). Titles of identified articles were then checked for relevance by the same author within Rayyan®. Abstracts of identified articles were then checked for relevance by two independent reviewers (BT and HC) (136). The remaining articles were extracted from Rayyan® and exported into Microsoft Office Excel (Microsoft Corporation, Washington, USA) where full-text articles were then retrieved and reviewed in accordance with the set of inclusion criteria. This process was completed by two independent reviewers (BT and HC) (137). Any disagreements on study inclusion were then reviewed separately by a third independent reviewer (MR).

2.2.2 Inclusion and Exclusion Criteria

This review employed PCO from the PICO (participants, intervention, comparison, outcome) mnemonic framework for the assessment of study inclusion, because interventions were not of importance within this review (138):

P: (a) children, adolescents and adults; (b) habitual video gaming players and/or E-athletes; (c) males and/or females; (d) no medical condition, illness or disease (e.g., no research focussing on physical disability, developmental coordination disorder etc.); (e) exposure to gaming was at least 7 weeks (139);

C: comparing HRCoF between either (f) video gamers and non-gamers; (g) different video gamer skill levels/expertise; (h) different genre video gamers;

O: (i) quantifiable data and results of components of fitness measured via validated methods (e.g., reaction time, coordination, strength, power, flexibility, balance, cardiovascular endurance).

See Figure 2.1 for study exclusion at each systemic stage.

2.2.3 Risk of Bias

In order to assess the risk of bias within the included studies, the Newcastle-Ottawa Scale (NOS) was employed to assess the methodological quality of the studies (140), a copy of the NOS is attached within the Appendix (see Appendix 1). Nos is designed for observational studies and assesses multiple domains (selection, comparability, exposure/outcome) allowing for robust quality thresholds, therefore is valid within the cohort and methodology of the articles being assessed (140). NOS is a star scoring system with three main categories of 1) selection, 2) comparability and 3) outcome. Within these there are specific items and each item is ranked in terms of the methodological approach implemented, where the most rigorous is given a star. The minimum stars awarded to a study is 0 where the maximum score is 9 stars. The NOS scoring uses a threshold system: scores of 7-9 stars are considered ‘low risk of bias’ or high quality, 4-6 stars are considered ‘unclear risk of bias’ or fair quality, and 0-3 stars are considered ‘high risk of bias’ or poor quality. A total score of 7 or more stars was required to be included in this review and met study threshold quality. Any scores that did not meet this minimum threshold were excluded on the bases of poor study quality and risk of bias. While the exclusion of lower-quality studies may reduce the breadth of available evidence and introduce potential threshold bias, the approach was necessary to enhance the validity and reliability of the review findings by minimising the influence of studies with substantial methodological limitations. The NOS was completed by two independent reviewers (BT and HC). The interrater reliability was assessed using a Bland-Altman plot with 95% limits of agreement (141). If any agreement scores were outside the 95% limits of agreement, a third independent reviewer (MR) would independently complete the NOS for the studies in question.

2.2.4 Data Extraction

Data extraction was completed by BT. A final list of the included articles was created within Microsoft Office Excel. The following information was extracted and put into a table: (1) year of publication; (2) participant demographics (e.g., age and sex); (3) comparison made (e.g., control group, VGP versus non-VGP, action genre VGP versus sport genre VGP); (4) methodological details (e.g., HRCoF measures); and (5) the key outcomes/findings (e.g., reported differences in components of fitness between comparison groups).

2.3 Results

A total of 26,711 potentially relevant articles were identified using the database searches over three databases. After removing records through filtering and deduplication, 7057 studies were screened, where 53 studies met initial satisfaction and were then subjected to the PCO criteria checks. One disagreement on study inclusion was reviewed by the third independent reviewer and was included. A final 10 studies met the inclusion criteria with 6 studies passing the risk of bias check that would be included in this review. Overall, these 6 studies were published during a period from February 2017 to October 2024.

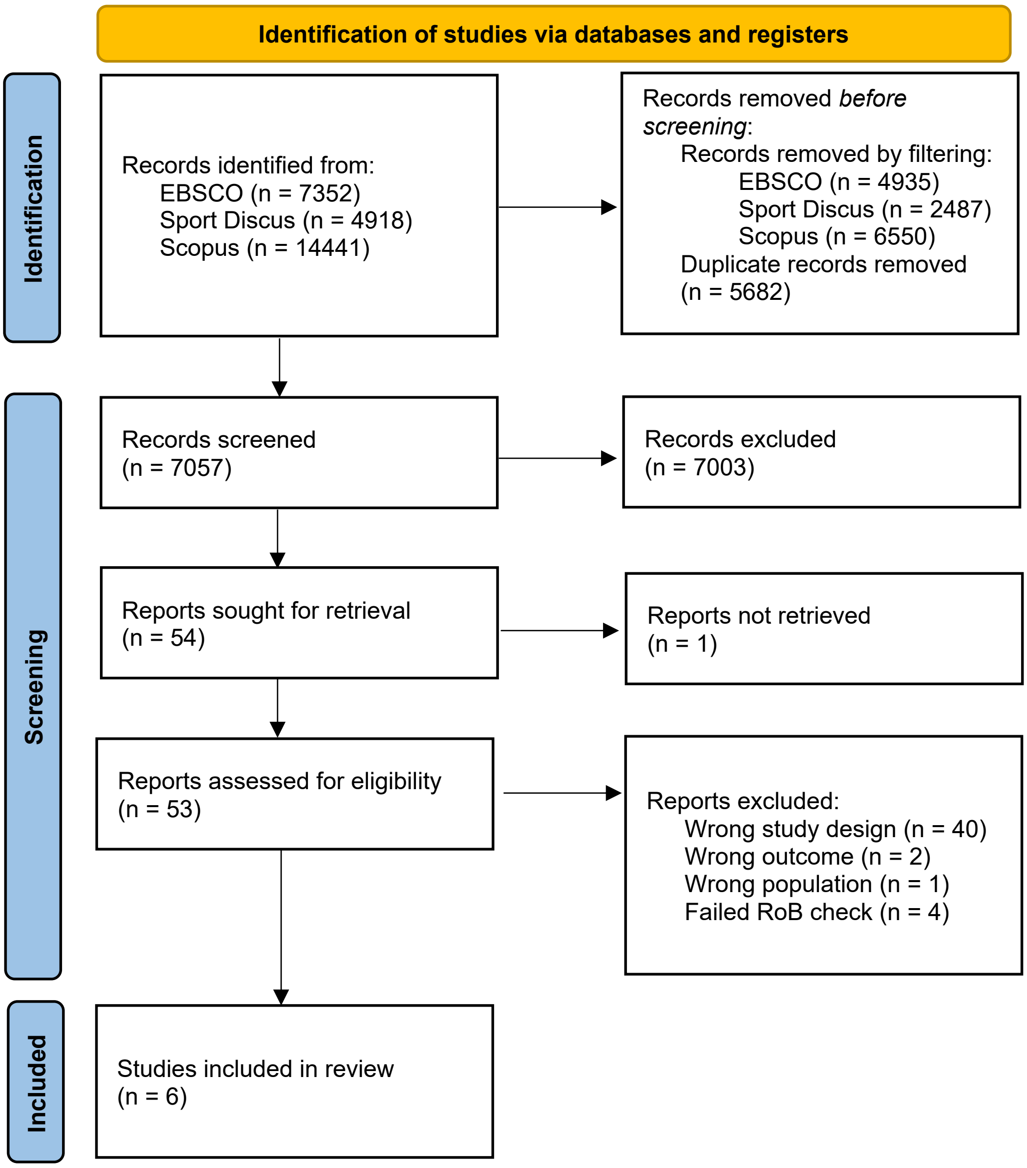

Figure 2.1: Flow diagram of studies through the review process.

2.3.1 Risk of Bias Assessment

The NOS score along with the Bland-Altman plot with 95% confidence intervals were completed for the 10 studies to test their methodological quality and risk of bias. The Bland-Altman plot revealed more than 95% agreement between the two reviewers (BT and HC). Figure 2.2 displays the Bland-Altman plot and Table 2.1 displays the NOS scores for the selected studies all meeting agreement.

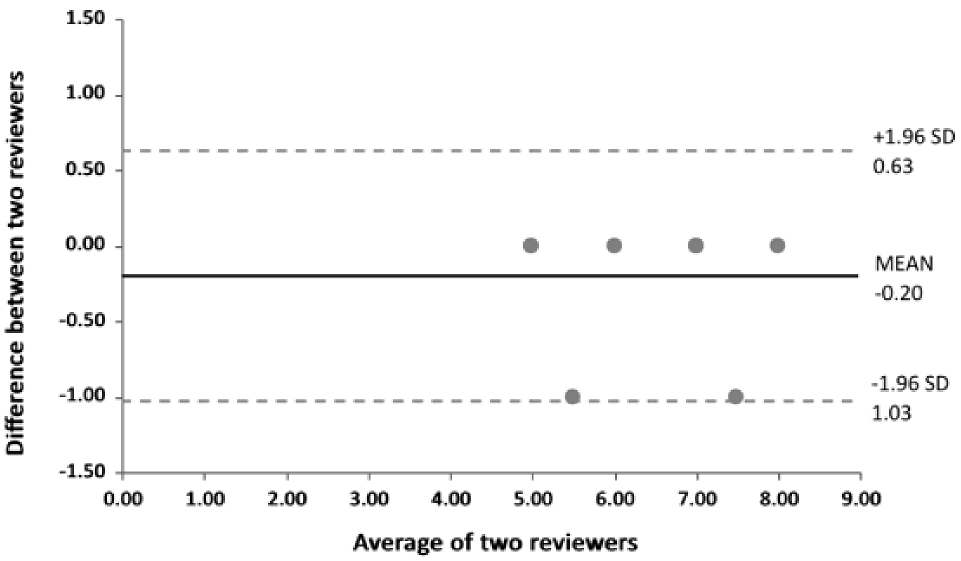

Figure 2.2: A scatter graph displaying the Bland-Altman plot comparing the NOS scores between two reviewers. The black line is the mean difference between the scores, and the grey dotted lines are plotted at the limits of agreement calculated as $\pm$ 1.96 times the mean standard deviation.

The NOS score of four of the studies was 5 or 6, therefore they were not included within the review due to poor quality and high risk. These four studies were not included due to a variety of two or three of the following reasons; not acquire vital participant information reliably, not control for age and/or sex, or no description of the selection of the non-exposed cohort. The NOS score of six of the studies was 7 or 8, with an overall mean score across all six studies of 7.33 $\pm$ 0.52.

2.3.2 Population and Comparison

Across the six included studies there were 376 participants, 74 female and 302 male, aged from 17 to 39 years old and the sample size ranged from 36 to 98 participants, refer to Table 2.2 for more information. Of the included studies two compared habitual-VGP and non-VGP (142,143), one compared E-athletes, traditional physical athletes and non-VGP (102), two compared across E-athletes of different expertise levels (103,144),and one compared across habitual-VGP of different genre game types (78).

Regarding the relevant VG expertise, Delmas et al. (142) identified habitual-VGP and their expertise through their in-game official rankings in 'League of Legends'. Guney et al. (143) employed survey forms to identify habitual-VGP who played VG for a minimum of four hours per day for at least the past 6 months. Luu et al. (102) identified E-athletes through their in-game rankings of between gold and diamond, and who had played VG for at least two years. Ersin et al. (103) used structured interviews to identify more experienced E-athletes who play VG for more than 14 hours per week compared to less experienced E-athletes who play less VG per week. Toth et al. (144) identified E-athletes and their expertise through their in-game official rankings in 'Counter-Strike: Global Offensive'. Deleuze et al. (78) employed questionnaires to identify habitual-VGP preferred genre of VG and mean time spent playing their preferred genre per week.

2.3.3 Outcomes

In the literature there were three HRCoF that have been explored; reaction time, flexibility and strength.

Reaction Time

Guney et al. (143) and Luu et al. (102) found that VGP had 11.12% significantly faster reaction times than non-VGP, through the BlazePod Trainer Device, and through a computer generated colour cue test and the ruler drop test, respectively. However, Delmas et al. (142) found no significant difference between multiplayer online battle arena (MOBA) habitual-VGP and non-VGP, through eye tracking equipment measuring reaction time by searching for targets in visual scenes under uncluttered and cluttered conditions.

Ersin et al. (103) and Toth et al. (144) found that high and elite skilled E-athletes had 15.13% significantly faster reaction times than intermediate and low skilled E-athletes, through the Human Benchmark website Reaction Time Test and the Colour-Word Stroop Test, respectively. Deleuze et al. (78) found that first person shooter (FPS) habitual-VGP had significantly faster reaction times than MOBA habitual-VGP, through the Hybrid-Stop Task.

Flexibility and Muscle Strength

Guney et al. (143) employed a digital goniometer to measure shoulder flexibility and found non-dominant shoulder flexion flexibility was significantly greater in habitual-VGP than non-VGP. This study also employed a digital dynamometer to measure shoulder muscle strength and found non-dominant shoulder hypertension muscle strength was significantly greater in non-VGP than habitual-VGP (143).

Table 2.2 displays the summary of findings of the included studies with specific means, standard deviations and p-values.

Table 2.1: Risk of bias check using the Newcastle-Ottawa scale.

Study (Author, Year)	Selection (0-4)	Comparability (0-2)	Outcome (0-3)	Total Stars (0-9)	Quality Rating
Delmas et al., 2021 (142)	****	*	**	7	High
Guney et al., 2024 (143)	***	**	**	7	High
Luu et al., 2021 (102)	****	**	**	8	High
Ersin et al., 2022 (103)	****	**	**	8	High
Toth et al., 2019 (144)	****	**	*	7	High
Deleuze et al., 2017 (78)	***	**	**	7	High

Table 2.2: Summary of findings.

Study (Author, Year)	**Population**	**Comparison**	**Outcome (HRCoF Measurement)**	**Outcome (Results)**
Delmas et al., 2021 (142)	n = 58 (34 males, 24 females) aged 22.3 ± 2.9. MOBA H-VGP = 28. Non-VGP = 30	MOBA vs Non.	Searching for targets in visual scenes under two clutter conditions (uncluttered and high clutter) to measure reaction time.	No difference between MOBA H-VGP and non-VGP reaction time (p = 0.40).
Guney et al., 2024 (143)	n = 50 (females). H-VGP = 25, aged 17.36 ± 3.30. Non-VGP = 25, aged 20.48 ± 4.57.	H-VGP vs Non.	Shoulder flexibility was measured using a digital goniometer. Shoulder muscle strength was measured using a digital dynamometer. Reaction time was measured using BlazePod's.	Non-dominant flexion flexibility: H-VGP = 194.7 ± 9.84°. Non-VGP = 188.8 ± 10.09°. Significant difference, p = 0.042. Non-dominant hyperextension strength: H-VGP = 68.25 ± 11.52 N. Non-VGP = 78.62 ± 10.79 N. Significant difference, p = 0.002. Reaction time: H-VGP = 421.36 ± 30.40 ms. Non-VGP = 440.08 ± 31.57 ms. Significant difference, p = 0.038.
Luu et al., 2021 (102)	n = 36 (males) aged 18-22. E-athletes = 12. Athletes = 12.	E-athletes vs Athletes vs Control.	Visual reaction time was measured using a computer generated colour	Colour cue test: E-athletes = 269.83 ± 23.46 ms. Athletes = 276.50 ± 28.02 ms. Control = 290.83 ± 36.50 ms.

	Control (non-VGP and non-athletes) = 12.		cue test and the ruler drop test.	Significant difference between E-athletes and Control, $p < 0.05$. Ruler drop test: E-athletes = 174.58 ± 26.14 ms. Athletes = 186.94 ± 20.30 ms. Control = 223.47 ± 31.11 ms. Significant difference between E-athletes and Control, $p = 0.0002$.
Ersin et al., 2022 (103)	n = 53 (males). High experience E-athletes = 28, aged 22.5 ± 1.97. Low experience E-athletes = 25, aged 23.16 ± 1.49.	High experience vs low experience.	The reaction time test was used to evaluate reaction time on the Human Benchmark website.	High experience = 227.13 ± 33.15 ms. Low experience = 278.67 ± 45.44 ms. Significant difference, $p < 0.001$.
Toth et al., 2019 (144)	n = 98 (males). Low skill E-athletes = 12, aged 19.42 ± 3.44. Intermediate skill E-athletes = 26, aged 20.46 ± 4.16. Elite skill E-athletes = 60, aged 19.77 ± 3.84.	Low skill vs Intermediate skill vs Elite skill.	Colour-word stroop task to measure reaction time.	Low skill = 814.84 ± 229.00 ms. Intermediate skill = 889.21 ± 248.67 ms. Elite skill = 784.59 ± 218.02 ms. Significant difference between low and intermediate to elite, $p < 0.001$.
Deleuze et al., 2017 (78)	n = 81 (males) aged 22.07 ± 3.83. MMORPG H-VGP = 20, aged 22.90 ± 3.39.	MMORPG vs MOBA vs FPS.	The Hybrid-Stop Task, go trials measuring reaction time over 160 trials.	MMORPG = 501.71 ± 220.88 ms. MOBA = 525.04 ± 243.42 ms. FPS = 363.85 ± 43.81 ms. Significant difference between MOBA and FPS, $p < 0.05$.

	MOBA H-VGP = 36, aged 21.06 ± 1.79. FPS H-VGP = 25, aged 22.88 ± 5.69.

Note. All results are given as mean ± standard deviation and ages are given in years. HRCoF health-related components of fitness. H-VGP habitual video gaming player. VGP video gaming player. MOBA multiplayer online battle arena. MMORPG massive multiplayer online role-playing games. FPS first person shooter.

2.4 Discussion

This study aimed at collating and synthesising the current literature on the implications of VG across HRCoF within both E-athletes and habitual-VGP. Hence, a systematic literature review was conducted in accordance with the PRISMA guidelines and NOS risk of bias assessment, finding 6 studies were eligible for review. Overall, the findings provide insights showing how VG can impact various HRCoF.

The results from this systematic literature review found that, Guney et al. (143) was the only study to include physiological HRCoF outcomes, shoulder flexibility and muscular strength. It was reported that habitual-VGP had significantly greater non-dominant shoulder flexibility ($p = 0.042$) although reduced non-dominant hyperextension strength ($p = 0.002$) than non-VGP (143). This shows that VGP have more imbalances than non-VGP within flexibility and strength. This imbalance in flexibility and strength could be caused by maintaining static posture alongside abnormal repetitive movements while VG, which can cause elongations within various muscles while others are in shortened positions (143). It is important to note that this study by Guney et al. (143) did not include males, as the sample was from a female volleyball team, which does limit the comparability between this and other studies within this review which are male-dominated populations.

In addition to the physiological HRCoF outcomes, Guney et al. (143) observed significantly faster reaction times in habitual-VGP than non-VGP ($p = 0.038$), and this was corroborated by Luu et al. (102) within E-athletes ($p < 0.001$). Although, these two studies found similar results, they used a variety of different assessment tools, including BlazePod's, a reactive light-based system, computer-based colour cue tasks, and ruler drop tests. Additionally, the populations within these two studies were different, one female habitual-VGP (143) and the other male E-athletes (102), though they were all young adults. However, these findings do indicate that consistent engagement in VG could be associated with enhanced perceptual-motor processing speeds, which could be attributed to the repeated exposure to time-sensitive decision-making to rapid visual stimuli environments typically encountered with VG (101,142). Hence, the implications of VG upon HRCoF could be independent of sex, given Guney et al. (143) and Luu et al. (102) found similar results within females and males. Additionally, these faster reaction times could be due to some VGP performing over 500 actions per minute while VG, which is approximately 200-470 actions per minute above typical daily activities actions per minute (143). Moreover, faster saccadic peak velocities (eye movement between fixation points) found in VGP would give an advantage when responding to rapid visual stimuli, causing faster reaction times (102).

However, Delmas et al. (142) reported finding no significant difference in reaction time between MOBA habitual-VGP and non-VGP. Another different methodology was used to test RT, searching for visual stimuli in cluttered and uncluttered conditions, which could account for this discrepancy within the literature. Visual search tasks can require more focussed attention and increased cognitive loads, unlike the previous more simple RT tests used by Guney et al. (143) and Luu et al. (102), which could explain the inconsistency across these studies. This brings to light the importance of the specificity of HRCoF tests when interpreting reaction time, if the methodology used is similar to the main demands of VG.

Evidence from the studies examining VG skill level and experience demonstrates an association of higher skill/expertise and faster reaction time. Ersin et al. (103) reported that highly experienced E-athletes had significantly faster RT than less experienced E-athletes. Similarly, Toth et al. (144) reported that elite skill level E-athletes had significantly faster RT than intermediate and low skill level E-athletes ($p < 0.001$). It has been suggested that this could be due to less expertise in the mechanics of using a mouse and keyboard or controller, therefore, causing slower RT through physicality within the lower skilled compared to elite skilled E-athletes (144). These findings suggest that prolonged engagement in VG, requiring repeated quick stimulus response, could contribute to long-term adaptations to reduce reaction time (103).

Although these findings are consistent, it is unclear whether greater VG experience and skill level directly lead to quicker RT, or whether individuals with naturally quicker RT will become better skilled and experienced VGP. This could be due to the observational nature of these studies, causing this limited causal interpretation (103,144). In addition, various factors were not consistently controlled, for example, VG duration and genre-specific demands, therefore while the evidence demonstrates an association between reaction time and skill level in VG, any absolute conclusions cannot currently be made.

However, only one study focussed on the variations between VG genres, Deleuze et al. (78) identified that FPS habitual-VGP had faster reaction time than MOBA and massive multiplayer online role-playing games (MMORPG) habitual-VGP, though was only significantly faster than MOBA habitual-VGP. This could reflect the specific demands of FPS VG, requiring quick motor responses to visual dynamic stimuli, compared to MOBA and MMORPG VG requiring decision-making for longer time periods using strategic planning and team coordination, reducing the need for the same rapid responses as FPS habitual-VGP. Furthermore, these findings could help explain the non-significant findings of Delmas et al. (142), where no difference was found between MOBA habitual-VGP and non-VGP reaction times.

Across the six studies heterogeneity can be seen, which is likely attributed to variations in methodological procedure and classification of video gamers. The included studies used a wide variety of protocols to assess reaction time, from more simple measurements, for example the ruler drop test (102), to more complex cognitive demanding measurements, for example the Stroop task (144), therefore limiting the comparability between studies. Differences in the criteria to categorise an individual as a VGP or a VGP with less or more exposure, further contribute to the variability within evidence found within these six studies. Sample sizes across studies were small, averaging 62 and ranging from 36 to 98 participants, and only two studies included females (142,143). Sample sizes need to increase to allow more concrete conclusions to be made and increase the ability to apply these conclusions to the wider population. Delmas et al. (142) included 34 males and 24 females and Guney et al. (143) included 50 females, while the two studies with the highest populations, 81 and 98, were all males. This increases the risk of selection bias and decreases the ability to apply the findings across the wider population. However, all six studies included young adults, ranging from 17.36 $\pm$ 3.30 to 23.16 $\pm$ 1.49 years old, which is positive as young adults are one of the key demographics of VG. However, these findings exclude other aged groups, such as adolescents, which are also one of the key demographics of VG, as seen by 91% of adolescents engaging in VG (111).

As previously discussed within 2.1, there are inconclusive findings regarding VGP HRCoF levels, warranting a systematic review for comprehensive synthesis of findings, which appear to be worse than previously understood, with major gaps within the literature having been identified. Additionally, many other physiological and cognitive HRCoF levels in VGP have not been covered, for example, cardiovascular endurance, power, balance, and coordination. However, cardiovascular endurance has been found to improve within adults and children over 6-week, 8-week, and 12-week active video gaming (active-VG) interventions using the Xbox Kinect, Playpulse and Xbox 360 devices, respectively (145-147). Balance has been found to improve in adults over 4-week and 8-week active-VG interventions using the Xbox Kinect and Nintendo Wii devices, respectively (148,149). Coordination has been found to improve in adolescents over a 5-day virtual reality active-VG intervention (150). However, these studies were not included within this review due to them being interventions, meaning they were not focused on the relationships between VGP and their HRCoF. Additionally, these studies' participants were those who had not engaged in VG prior to participation and included an active-VG intervention, instead of VGP and sedentary VG which this review was focussed on. Moreover, these outcomes may not have been considered for VGP within the current literature due reaction time being the key consideration for VG performance. Therefore literature has focussed on this, which could be due to the vast monetary incentive of million dollar cash prises, as discussed in 1.1.2, to excel in VG and Esports. However, these other HRCoF are important to consider in both E-athletes and habitual-VGP due to their associations with health, as discussed in 1.4, greater HRCoF levels are associated with lower all-cause mortality and risk of stroke, and improved mobility and executive function (83-91). Hence, research measuring a wide range of HRCoF within VGP is required to assess their physiological and cognitive HRCoF levels. However, this review did find consistent reports of the association between faster reaction times in VGP to non-VGP and greater skilled to less skilled VGP, and imbalances within shoulder flexibility and muscle strength, which does suggest that reaction time could be a key HRCoF in VG performance.

2.4.1 Limitations and Future Recommendations

The main limitations of the current literature include, a limited number of included studies, which reduces the robustness and breadth of synthesis making it difficult to identify consistent patterns. Other limitations include limited HRCoF being tested and small sample sizes emanating from the literature, which therefore only provides an incomplete representation of overall HRCoF profiles in VGP and may reduce statistical power, limiting the confidence in the reported findings. The predominance of male and young adult participants across the included studies introduces potential selection bias and limits the generalisability of findings to other key demographic groups, such as females and adolescents. Additionally, the evidence on physiological HRCoF is derived from a singular study, and hence these should be considered as preliminary results, therefore more research is necessary to corroborate these findings and to investigate more physiological HRCoF.

Moreover, the main limitations of this review include, restriction to studies published in the English language, which could have results end in the exclusion of relevant research and introduced language bias. Although multiple databases were searched, the selection may not have captured all relevant studies, thereby limiting the comprehensiveness of the review. Despite these limitations, the review provides a transparent and structured synthesis of the available evidence, offering a valuable foundation for future research in this emerging field.

Future research should focus on a wider breadth of standardised HRCoF testing so that the overall health and fitness of VGP can be measured, include coverage of both male and female participants and a focus should be made in adolescents as they are a key demographic of VG and currently have no research attention. Examination of the shape of relationships between VG and HRCoF, whether that be linear or non-linear, or positive or negative relationships, is key to explore within adolescents. It is important that adolescents receive this attention within research because if we can intervene at the adolescent level, prevention of the negative health associations with VG (10-19,22,23-26,28,91,111-116) can be achieved and they will go into adulthood physically healthy with good habits to maintain this health.

2.4.2 Conclusion

This review provides evidence that participation in VG is associated with faster reaction time and conflicting results in HRCoF, particularly at high skill levels to flexibility and strength. Although, heterogeneity within results, methodologies, and sample population calls for caution in interpretation and as such the current findings are not definitive. Future research needs to prioritise wider assessments on these HRCoF measurements among larger sample sizes including females and adolescents.

Chapter 3: Relationships Between Adolescents' Video Gaming Duration and Health-Related Components of Fitness: a Generalised Additive Modelling Approach

Note about this Chapter

Whereas across most of this thesis physiological health-related components of fitness are addressed first, followed by cognitive health-related components of fitness, this Chapter (Chapter 3) is structured presenting cognitive health-related components of fitness first, followed by physiological health-related components of fitness. This is due to reaction time being the key health-related component of fitness identified in Chapter 2, and hence being able to hypothesise about reaction time.

3.1 Introduction

Video gaming (VG) is mainly a sedentary activity where players control on-screen actions via input devices with visual and auditory feedback. VG uptake soared in 2020 with the onset of COVID-19 with total internet traffic increasing by 60% with a peak of 2.7 billion VG players (VGP) worldwide, and it was reported in 2021 by Ofcom that 76% of 12-15 years olds and 71% of 16-24 year olds engage in VG (6,7,151).

The importance of adolescents' health-related components of fitness (HRCoF) levels upon their growth and health is well established (152-154). Muscular fitness has been associated with skeletal health and quality of life (152,154). Low risk to cardio-metabolic health had also been associated with improvements in muscle endurance, lower limb power, and agility (154). It is also well documented that higher levels of sedentary behaviour, specifically screen-based activities such as VG, are associated with adverse developmental, physical and mental outcomes in adolescents (155,156). These outcomes can include impaired skeletal muscle and cognitive function development, obesity, reduced bone mineral density, lower insulin sensitivity, diminished psychosocial functioning and poorer academic achievement, with evidence showing a dose-response relationship (156-160).

Chapter 2 concluded that the current literature focussing on VGP HRCoF levels is limited, only three HRCoF have been tested within VGP, reaction time (RT) being the most common and only one study tested shoulder muscle strength and flexibility (78,102,103,142-144). The general consensus is that faster RT are seen in VGP than non-VGP, and the higher-skilled VGP the faster RT becomes (102,103,143,144). The limited evidence of reduced shoulder muscle strength and increased shoulder flexibility within habitual-VGP from one study, cannot be considered as definitive and requires more exploration (143). Additionally, the majority of the current literature consists of small sample sizes, typically including male adult VGP.

Therefore, the gap within the literature found is adolescent habitual-VGP and comprehensive testing of their HRCoF levels. Adolescence is a crucial period of life, since dramatic changes, physiological and psychological, take place at this age (152). Additionally, high fitness and PA levels in adolescence are significantly associated with continued high fitness and PA levels into adulthood, which is advantageous given that low levels of fitness in adulthood are related with several chronic diseases and mortality (161,162). With VG being a popular activity within adolescents, it is therefore important to explore the relationship between VG usage and HRCoF within this cohort. Current literature outlines the inverse relationship between decreased sedentary screen time, for example television viewing, and increased physiological HRCoF, for example muscular strength (163). However, due to the acute physiological demands of VG, outlined in Chapter 1, demonstrating VG is not a passive activity, these findings cannot be directly applied to VG. Conversely, VG is mainly a sedentary activity, and hence these findings make it appropriate to predict relationships between VG and HRCoF.

A range of cognitive and physiological HRCoF were assessed to provide a comprehensive evaluation of the potential associations between VG and HRCoF levels in adolescents. Reaction time was included due to its well-established association with VG, with gaming often shown to enhance visual processing speed and stimulus–response performance (78,102,103,143,144). Coordination was selected as it reflects the integration of cognitive and motor processes, which may be influenced by the visuomotor demands of gaming tasks (83,84,109). Balance was included due to its reliance on neuromuscular control and postural stability, which may be negatively affected by prolonged sedentary behaviour and reduced engagement in weight-bearing activity (91). Flexibility was assessed given that extended periods of static sitting, characteristic of gaming, may contribute to reduced joint range of motion and increased musculoskeletal stiffness (90). Lower-body power, as assessed via jump height, was included as an indicator of muscular function that may be diminished through reduced participation in PA (154). Finally, handgrip strength was measured as a marker of overall muscular strength and general health, but also due to its relevance to repeated fine motor engagement during gaming (87-89,152,154). Collectively, these variables allow for the assessment of both potential positive and negative associations with VG behaviour.

Generalised additive modelling (GAM) offers an appropriate sophisticated method for exploring the extent and shape of currently unknown relationships between VG duration and HRCoF. GAM allows for high flexibility and complex relationships, which provides powerful interpretations of relationships found. However, this requires greater, more robust sample sizes than seen in the results of Chapter 2, which could explain why this relationship is yet to be explored using such a statistical method.

Therefore, it is imperative to address the gap within the current literature found in Chapter 2, due to the popularity of sedentary VG and importance of HRCoF levels within adolescents (7,152,154). Hence this study aims to assess the relationships between VG duration and various cognitive and physiological HRCoF, including reaction time, coordination, balance, flexibility, jump height and handgrip strength, within adolescents using generalised additive modelling to smooth these relationships; to then predict each HRCoF against weekly VG time in adolescents. Chapter 2 indicated that VG is associated with faster reaction times, therefore it is hypothesised that as weekly VG duration increases, reaction times will become faster; the other five HRCoF are exploratory.

3.2 Methods

This quantitative cross-sectional study was ethically approved by the researchers' institutional ethics sub-committee II from the University of Essex School of Sport, Rehabilitation and Exercise Sciences, with ethical approval code ETH2425-0909. All participants that were aged 18 years old or above provided participant informed written consent and all participants that were aged 17 years old or under provided parental informed written consent and participant assent. All participants completed a physical activity readiness questionnaire (PAR-Q) before taking part in the study.

3.2.1 Participants

This study consisted of 180 participants aged 12.89 $\pm$ 1.43 years old (80 male and 100 female; aged 13.0 $\pm$ 1.55 and 12.8 $\pm$ 1.32 years old, respectively) from secondary schools, colleges, and sixth forms. Participants were recruited though existing partnerships with the University of Essex. For participants from secondary schools, colleges and sixth forms, the participant/parental consent form Qualtrics survey (see Appendix 2) was sent out to the parents electronically through weekly email newsletters by the schools and paper copies (see Appendix 3) were given to students to take home to their parents to sign and return to school. Parents were required to complete and sign one version of the parental consent form. The participant assent form and PAR-Q Qualtrics survey (see Appendix 4) was completed by participants when they arrived for their testing session, which allowed participants to make their own informed decision to take part. For participants from universities, the participant/parental consent form Qualtrics survey was completed by participants upon arrival for their testing session. It was necessary that this was completed before any testing was to commence. Inclusion criteria for this study included being aged 11-19 years, no injuries identified and a positive score on the PAR-Q.

3.2.2 Procedure

Participants from secondary schools, colleges and sixth forms were required to complete one singular session of HRCoF testing during one of their school timetabled physical education lessons that was organised using a register. Upon arrival participants completed the appropriate assent/consent form and a PAR-Q via an Apple iPad Pro 2024 using iPadOS Version 18.5 software (Apple Inc, California, USA) that was preloaded in the form of a Qualtrics questionnaire. Items of this questionnaire were set to force response and therefore questions must be completed to move onto the next page. If participants could not complete the assent or consent form or any questions in the PAR-Q were scored negatively and inclusion criteria were not met, then the iPad would automatically notify the participant and researcher that the testing session would not commence and be excluded from the study. During this time, participants were free to ask any questions and highlight any concerns to the research team that was present. All participation was voluntary and participants were reminded that they could withdraw at any time.

Following successful completion of the initial inclusion task, participants would automatically be directed into a Qualtrics questionnaire survey (see Appendix 4), which included 16 questions to determine participants' VG and PA habits. Questions included 'Which console/PC do you use for video gaming?', 'How many hours per week do you spend on Xbox?', and 'In the past week, how many hours in total did you spend doing physical activity which was enough to raise your breathing rate?'. Questions were adapted from the Sport England Active Lives Questionnaire and

Milton et al. (164) single-item physical activity measure, and these questions have been found as reliable and valid (164,165). This approximately took 3 minutes to complete.

Once the Qualtrics survey was completed, a battery of fitness testing stations followed. This included anthropometric measurements and tests of reaction time, coordination, balance, flexibility, jump height, and handgrip strength. The six fitness tests included the psychology experiment building language (PEBL) simple reaction time, alternate-hand wall toss, standing stork, sit and reach, countermovement jump and handgrip dynamometer tests, respectively, and all have been found as reliable and valid measures, with ICC's ranging from 0.95 to 0.98 (166-172). There was no set order to the HRCoF tests, however, was not randomised either. Participants were guided through all anthropometric measurements and HRCoF tests, with an explanation of the test, instructions and demonstrations given before each HRCoF test. Participants were allowed one practice attempt at each HRCoF test, except for the reaction time test. Some encouragement was given to participants during HRCoF testing, such as 'that's great', 'good job', 'well done' etc. Once all tests were completed, participants were debriefed.

3.2.3 Anthropometric Measurement Tests

Participants were instructed to remove their shoes, step onto the height stadiometer (Mobile Height Measure Stadiometer, Seca, Birmingham, UK), and stand up straight with a deep breath in. The measurement needle was adjusted to just touch the top of the participants head and height (m) was recorded. Participants were then instructed to step onto the digital weighing scales (Digital Electronic Weighing Scale, Seca, Birmingham, UK) and body mass (kg) was recorded to two decimal places.

3.2.4 Reaction Time Test

The PEBL simple reaction time test was conducted on a HP Stream Laptop 14 (HP Inc, California, USA) using Window 10 Home (Microsoft Corporation, Washington, USA) software. PEBL is a simple programming language constructed to create and conduct various standard experiments, the simple reaction time test was edited to last for one block with 50 trials (173). Participants were instructed to press the X key in response to when they saw the X stimulus appear in the middle of the screen as quickly as possible. The delay between trials is automatically programmed to between 250ms to 2500ms, in 250ms increments five times each, these are randomised. If participants tried to anticipate a trial (less than 150ms) or took too long to respond to the stimulus (more than 3000ms), these trials are automatically discounted. A laptop mechanical keyboard configured to a UK QWERTY layout was used. The keyboard has standard membrane-based scissor-switch keys with an average travel distance of approximately 1.5mm. The typical input latency is approximately 15-30 milliseconds. The test was completed one time and the mean reaction time, computed over the 50 input trials, was recorded by the system.

3.2.5 Alternate-Hand Wall Toss Coordination Test

Participants were instructed to stand upright facing a straight flat wall one meter away. They were then instructed to underarm throw a standard tennis ball at the wall with one hand and catch it with the opposite hand, in a repeated motion (174). Participants had 30 seconds to throw and catch the tennis ball with alternating hands as many times as possible. When the tennis ball was thrown and caught this counted as one successful catch. If the tennis ball fell on the floor in front of them or next to them, participants were instructed to pick it up and carry on, however if the ball went out of arms reach, they were given another tennis ball and instructed to carry on. This procedure was completed three times and the highest score was recorded.

3.2.6 Standing Stork Balance Test

With their shoes off, participants were instructed from the anatomical position to place their hands on their hips, keep their back straight, raise one leg off the floor placing the bottom of the foot against the opposite knee, then raise their heel (plantar flexion) off the floor and hold that position for as long as possible (175,176). The timer started when the participant raised their heel off the floor and stopped when either their heel was placed back on the floor, their foot stopped connection with the opposing knee, or their hands came off their hips (175,176). This procedure was completed three times on both legs, the highest time of each leg was recorded, which were used to acquire a mean score recorded as peak balance (s). In cases of measurement error, a fourth trial was performed.

3.2.7 Sit and Reach Flexibility Test

With their shoes off, participants were instructed to sit down facing the sit and reach box (Sit and Reach Box, HaB Direct, Southam, UK), with the soles their feet flat against the box with toes pointing up (dorsiflexion), straight legs and knee's extended to approximately 180° for the duration of the test (174). Participants were then instructed to push a ruler with their fingertips, their hands side by side and palms facing downwards, from 0cm as far across the sit and reach box as possible and hold for two seconds then relax (174). This procedure was completed three times, the highest two scores were recorded and used to calculate mean flexibility (cm) (174). In cases of measurement error or poor agreement between measures, a fourth trial was performed.

3.2.8 Countermovement Jump Height

Countermovement jump height was assessed using a Jump Mat (Just Jump System, Perform Better, Southam, UK) and was calibrated according to manufacturer's guidelines. Within the jump mat's settings, 'Just Jump' was selected. Participants were instructed to stand in the middle of the mat with their feet shoulder width apart and place their hands on their hips, squat down to a 90° knee joint angle flexing the hips while maintaining a straight back, and jump up as high as possible in one smooth motion, keeping the knees extended to approximately 180°, landing in the same place as take-off (177). If these criteria were not met, the jump was repeated. This procedure was completed two times with the highest score recorded as peak jump height (cm). In cases of measurement error or poor agreement between measures, a third trial was performed.

3.2.9 Handgrip Strength Dynamometer Test

Muscular strength was assessed using isometric handgrip dynamometry (Takei TKK 5001 GRIP, Takei Scientific Instruments Co. Ltd, Tokyo, Japan). The dynamometer was periodically calibrated against known weights, and no evidence of drift was found. The dynamometer was adjusted to accommodate differences in hand size and ensure a comfortable grip position with the second metacarpals placed correctly on top of the grip-bar. Participants were instructed to sit down in an upright position with their forearm placed on the table in front of them in the mid prone position with their elbow flexed at 90° (178). Participants were instructed to use their dominant arm, if they did not know, they were instructed to use the arm they write with. Participants were instructed to squeeze the dynamometer as hard as possible giving a maximum effort for three seconds. This procedure was completed twice with rest time of 30 seconds, the highest score was recorded as peak grip strength (kg) (178).

3.2.10 Statistical Analysis

Microsoft Excel 365 (Microsoft Corporation, Washington, USA) was used to organise all data collected, calculate body mass index (BMI) from height (m) and mass (kg), see equation below, and identify means and highest values of HRCoF tests as appropriate. Descriptive statistics of participant characteristics and HRCoF calculations were performed using IBM SPSS 31 software and RStudio version 4.2.1 software was used for the remainder of the statistical analysis.

$BMI = mass\ (kg) / height^2\ (m)$

Smoothing curves were fitted using generalised additive modelling, which were developed using the R package “mgcv” (179,180). GAM was used to predict each HRCoF by VG hours per week. The GAM R script showing the process of creating the six models is attached as appendix 5.

Using the R package “segmented”, linear piecewise regression models were built to identify “breakpoints” or specific VG weekly times where the strength or direction of relationship between VG weekly time and the HRCoF changed to the greatest extent. Although data showed signs of non-normality, because we were interested only in identifying breakpoints and not in the form of the linear models, linear piecewise regression was considered appropriate. Visual inspection of the GAM graphs indicated zero or one main change in the data pattern, and consequently regression models were developed with one and two breakpoints.

If no breakpoints were identified, visual inspection of the GAM graphs lead to identifying points of a change within the relationship between the HRCoF and VG by identifying the derivatives of the graph, using the R package “gratia”, where appropriate for each GAM.

The target sample size was set to 165 participants, calculated using guidelines set out by Wood (2017) (179). Based on the anticipated complexity of the GAM (three smooth predictors with low to moderate complexity and one parametric predictor), the estimated total effective degrees of freedom (EDF) was approximately 11. To ensure stable estimation of smooth terms in the presence of high variability in HRCoF test outcomes, a conservative heuristic of 10-20 observations per EDF was applied (179). Accordingly, the target sample size was set to between 110 to 220 participants, see calculations below.

Smooth term complexity: low ~ 2 EDF, moderate ~ 4 EDF, high ~ 8 EDF

Parametric term: 1 EDF

Total EDF = low complexity smooth terms EDF + moderate complexity smooth terms EDF + high complexity smooth terms EDF + parametric terms EDF

Sample size = total EDF x observations per EDF

Smooth terms complexity: age = 2 EDF, physical activity hrs = 4 EDF, and VG hrs = 4 EDF

Parametric terms: sex

Total EDF = 2 + 4 + 4 + 1 = 11

Sample size = 11 x 10-20 = 110 – 220 participants.

3.3 Results

3.3.1 Descriptive Statistics

Anthropometric data, VG and PA habits of the participants are presented in Table 3.1. Descriptive statistics of HRCoF are presented in Table 3.2.

Table 3.1: Participant characteristics.

	Total (n = 180)	Females (n = 100)	Males (n = 80)
Age (years)	12.89 ± 1.43	12.81 ± 1.32	13.00 ± 1.55
Height (m)	1.60 ± 0.09	1.58 ± 0.08	1.62 ± 0.12
Body Mass (kg)	51.49 ± 11.03	51.06 ± 11.17	52.03 ± 10.88
BMI (kg/m^2)	19.9 ± 3.44	20.24 ± 3.67	19.67 ± 3.12
PA (h/week)	3.70 ± 2.05	3.54 ± 2.13	3.91 ± 1.92
VG (h/week)	8.34 ± 12.30	3.87 ± 8.66	13.93 ± 13.86

Note. Values are mean ± standard deviation. BMI body mass index, PA physical activity, VG video gaming.

Table 3.2: Descriptive statistics of health-related components of fitness.

HRCoF	Overall (n = 180)	Females (n = 100)	Males (n = 80)
Reaction Time (ms)	339.68 ± 52.77	343.73 ± 58.99	334.61 ± 43.60
Coordination	21.43 ± 7.79	19.71 ± 8.08	23.59 ± 6.87
Balance (s)	5.29 ± 3.89	5.60 ± 4.58	4.90 ± 2.79
Flexibility (cm)	16.88 ± 8.87	20.47 ± 8.69	12.39 ± 6.84
Jump Height (cm)	35.63 ± 7.88	34.45 ± 7.59	37.12 ± 8.03
Handgrip Strength (kg)	25.68 ± 6.36	24.63 ± 5.41	27.00 ± 7.19

Note. Values are mean ± standard deviation. HRCoF health-related components of fitness.

3.3.2 Generalised Additive Models

The results of the generalised additive models for each HRCoF are presented in Table 3.3. Visual inspection of the graphs of the smooth terms that statistically contribute to the HRCoF generalised additive models indicated the direction which they contribute to the model, this is displayed in Table 3.3. The results of the parametric coefficients for each generalised additive model are presented in Table 3.4.

Generalised additive models showed that the smooth terms of VG, PA and age explained a percentage of the deviance within each HRCoF: reaction time 16.8% (Figure 3.1); coordination 27.1% (Figure 3.2); balance 15% (Figure 3.3); flexibility 29.3% (Figure 3.4); jump height 15.5% (Figure 3.5); and handgrip strength 37.8% (Figure 3.6).

For breakpoint analysis, zero breakpoints were identified due to the smoothness of the generalised additive model graphs curves for coordination, balance, and jump height, and the linearity of the generalised additive model graphs for reaction time, flexibility, and handgrip strength. Therefore, derivatives were identified for coordination, balance, and jump height where the HRCoF relationship with VG time changed, see Figure 3.2, 3.3 and 3.5 respectively.

Table 3.3: Results from the generalised additive models for the six health-related components of fitness.

HRCoF	Smooth	n	EDF	F	p	Direction
Reaction Time	s(VG)	180	1	1.633	0.203	
	s(PA)	180	1	8.333	0.004*	↓
	s(age)	180	1.505	12.839	<0.001*	↓
Coordination	s(VG)	180	1.481	2.665	0.123	
	s(PA)	180	1.905	11.276	<0.001*	↑
	s(age)	180	2.707	7.183	<0.001*	↑
Balance	s(VG)	180	1.536	1.933	0.233	
	s(PA)	180	1.744	6.411	0.001*	↑
	s(age)	180	1.510	5.909	0.016*	↑
Flexibility	s(VG)	180	1	8.389	0.004*	↓
	s(PA)	180	1	6.225	0.013*	↑
	s(age)	180	1	6.934	0.009*	↑
Jump Height	s(VG)	180	1.484	0.840	0.539	
	s(PA)	180	1.176	1.706	0.143	
	s(age)	180	1	20.571	<0.001*	↑
Handgrip Strength	s(VG)	180	1	1.379	0.242	
	s(PA)	180	1	1.481	0.225	
	s(age)	180	4.498	16.481	<0.001*	↑

*Note. HRCoF health-related components of fitness, EDF effective degrees of freedom, VG video gaming, PA physical activity. * indicates statistically significant.*

Table 3.4: Results of the parametric coefficients of each generalised additive model.

HRCoF		Estimate	Std Err	t value	p value
Reaction Time (ms)	Intercept	340.25	5.160	66.71	<0.001
	Male	-1.28	8.053	-0.16	0.874
Coordination	Intercept	19.77	0.723	27.34	<0.001
	Male	3.74	1.163	3.22	0.002*
Balance (s)	Intercept	5.55	0.388	14.29	<0.001
	Male	-0.59	0.624	-0.95	0.344
Flexibility (cm)	Intercept	20.02	0.788	25.42	<0.001
	Male	-7.08	1.243	-5.69	<0.001*
Jump Height (cm)	Intercept	34.44	0.778	44.29	<0.001
	Male	2.68	1.244	2.16	0.033*
Handgrip Strength (kg)	Intercept	24.67	0.539	45.76	<0.001
	Male	2.28	0.856	2.67	0.008*

*Note. HRCoF health-related components of fitness, Std Err standard error. * indicates statistically significant.*

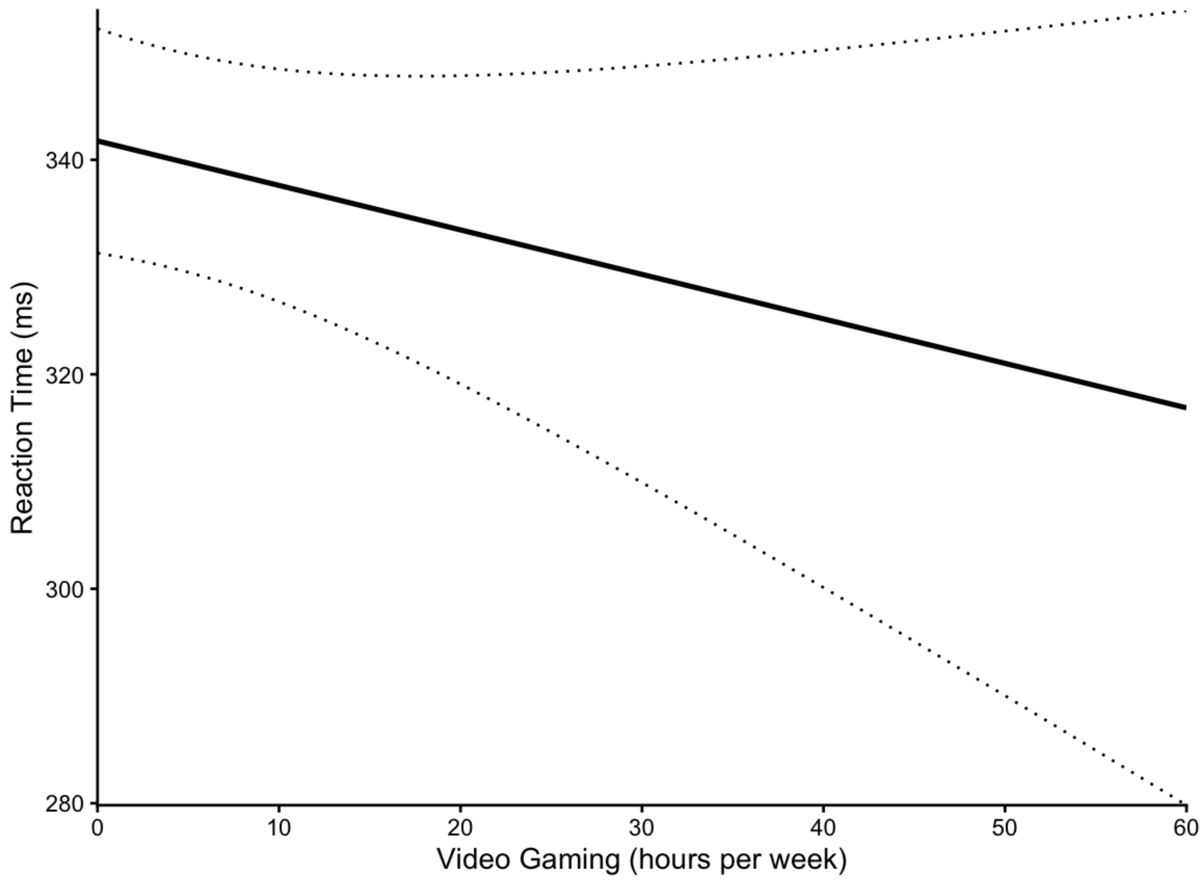

Figure 3.1: Predicted reaction time by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Video gaming did not significantly contribute to the reaction time generalised additive model (p = 0.203).

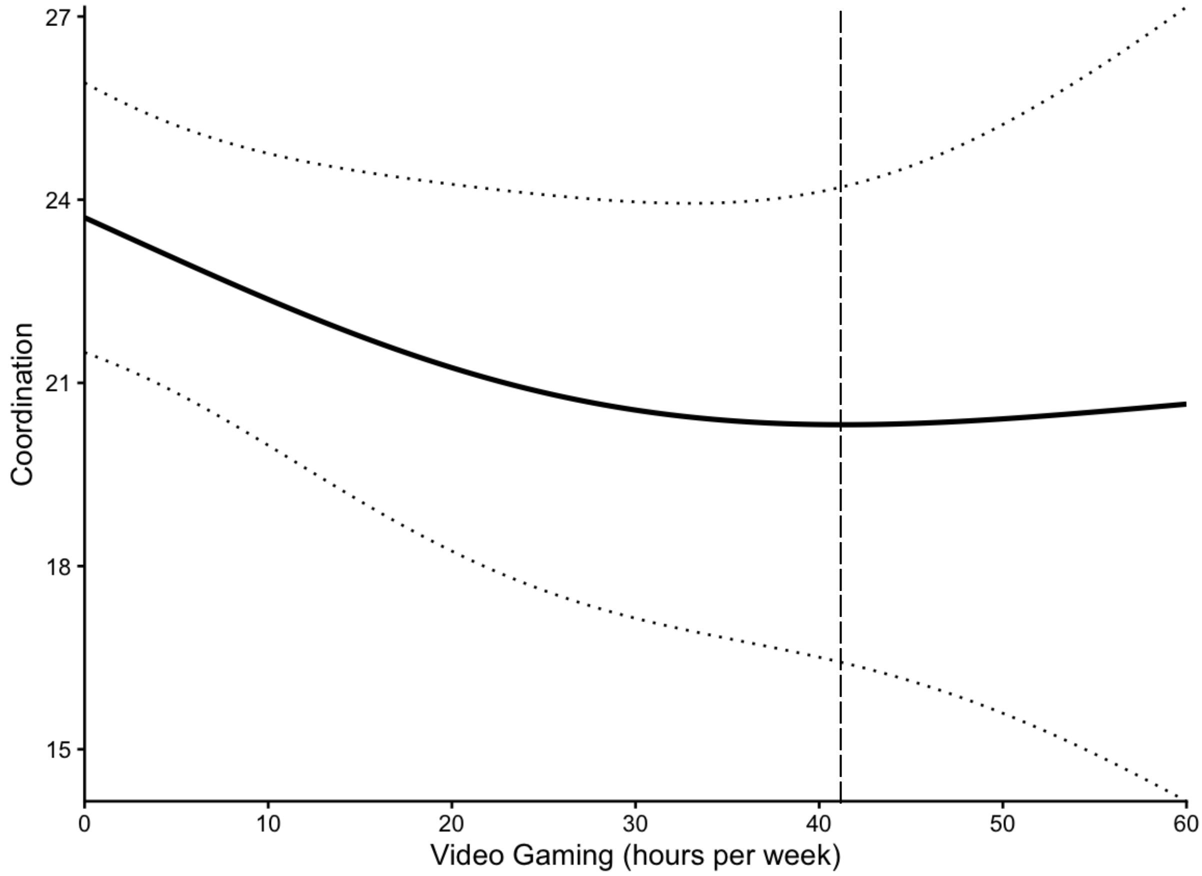

Figure 3.2: Predicted coordination by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Vertical dash line shows change of relationship at 41.31 h/week. Video gaming did not significantly contribute to the coordination generalised additive model (p = 0.123).

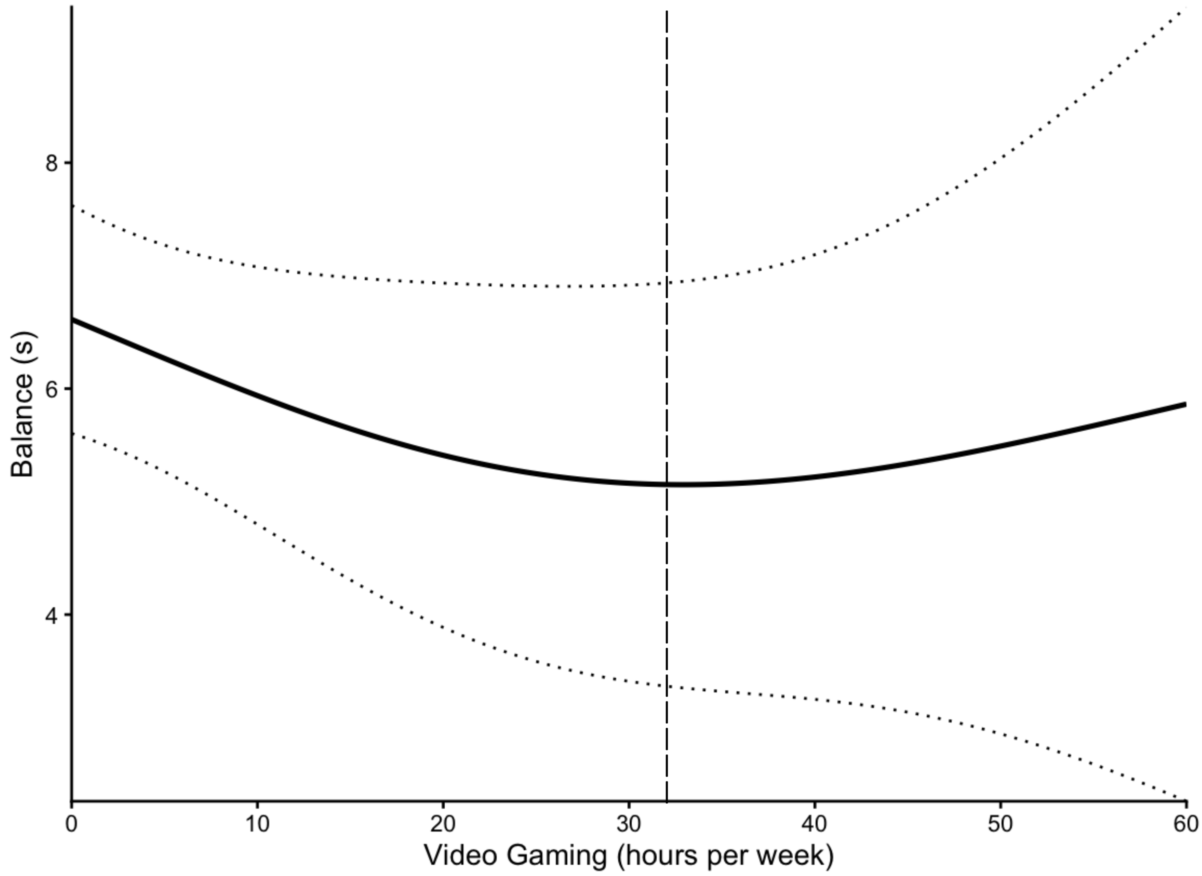

Figure 3.3: Predicted balance by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Vertical dash line shows change of relationship at 32.86 h/week. Video gaming did not significantly contribute to the balance generalised additive model (p = 0.233).

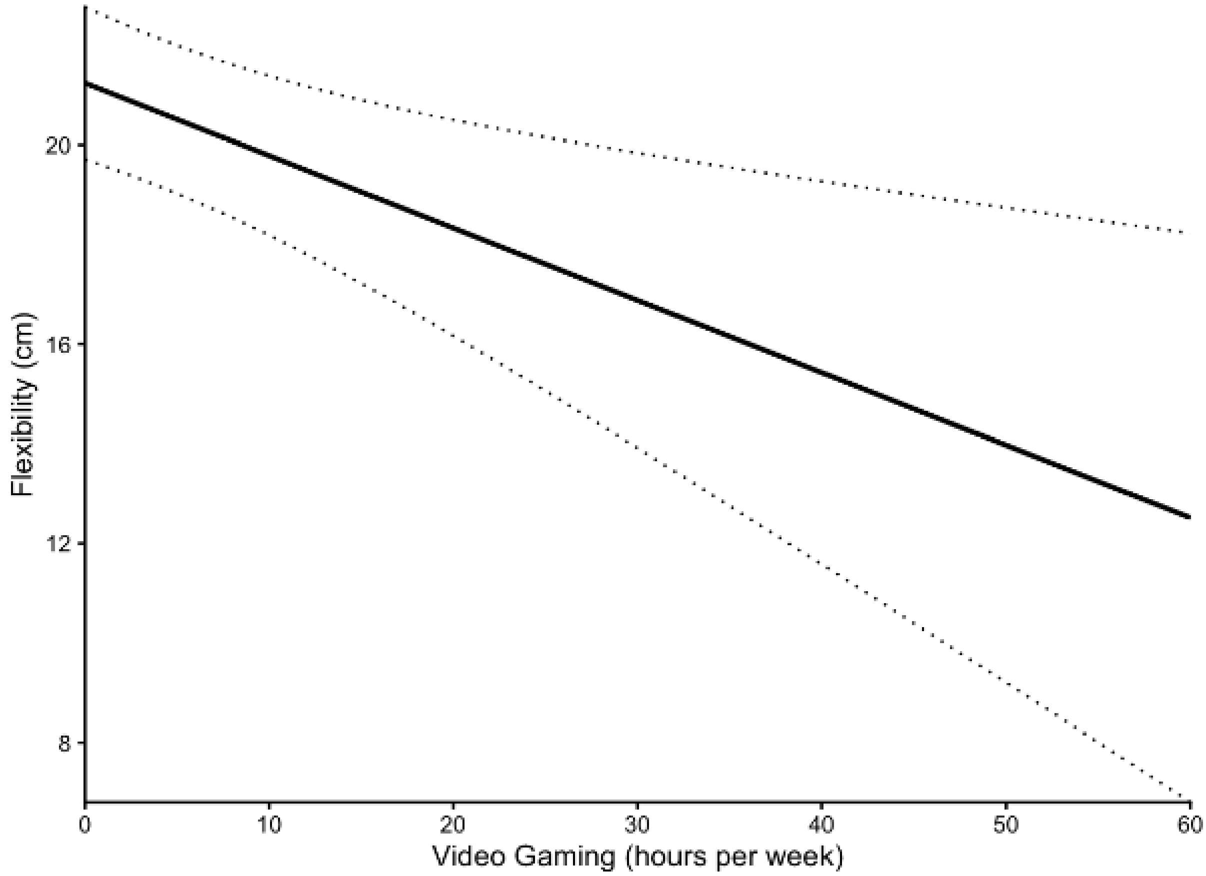

Figure 3.4: Predicted flexibility by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Video gaming did significantly contribute to the flexibility generalised additive model (p = 0.004).

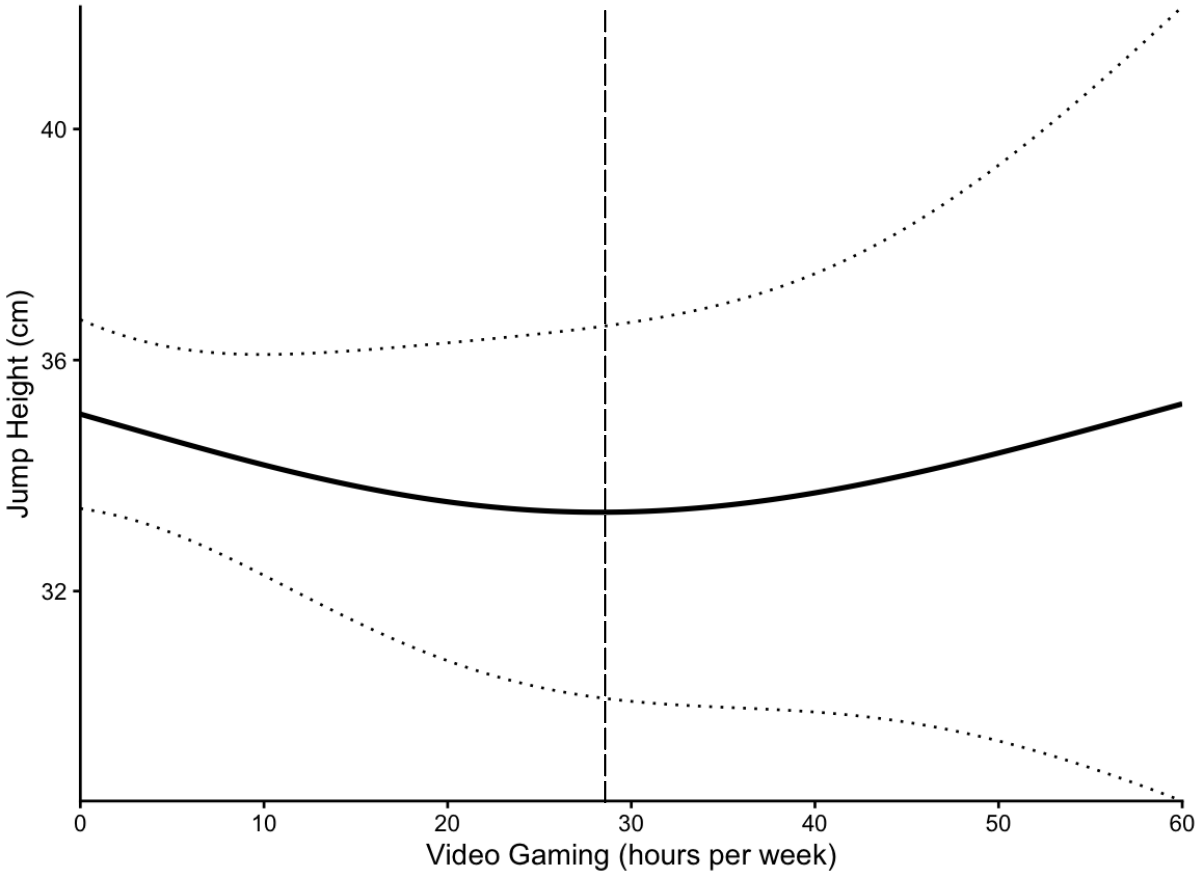

Figure 3.5: Predicted countermovement jump height by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Vertical dash line shows change of relationship at 28.04 h/week. Video gaming did not significantly contribute to the jump height generalised additive model (p = 0.539).

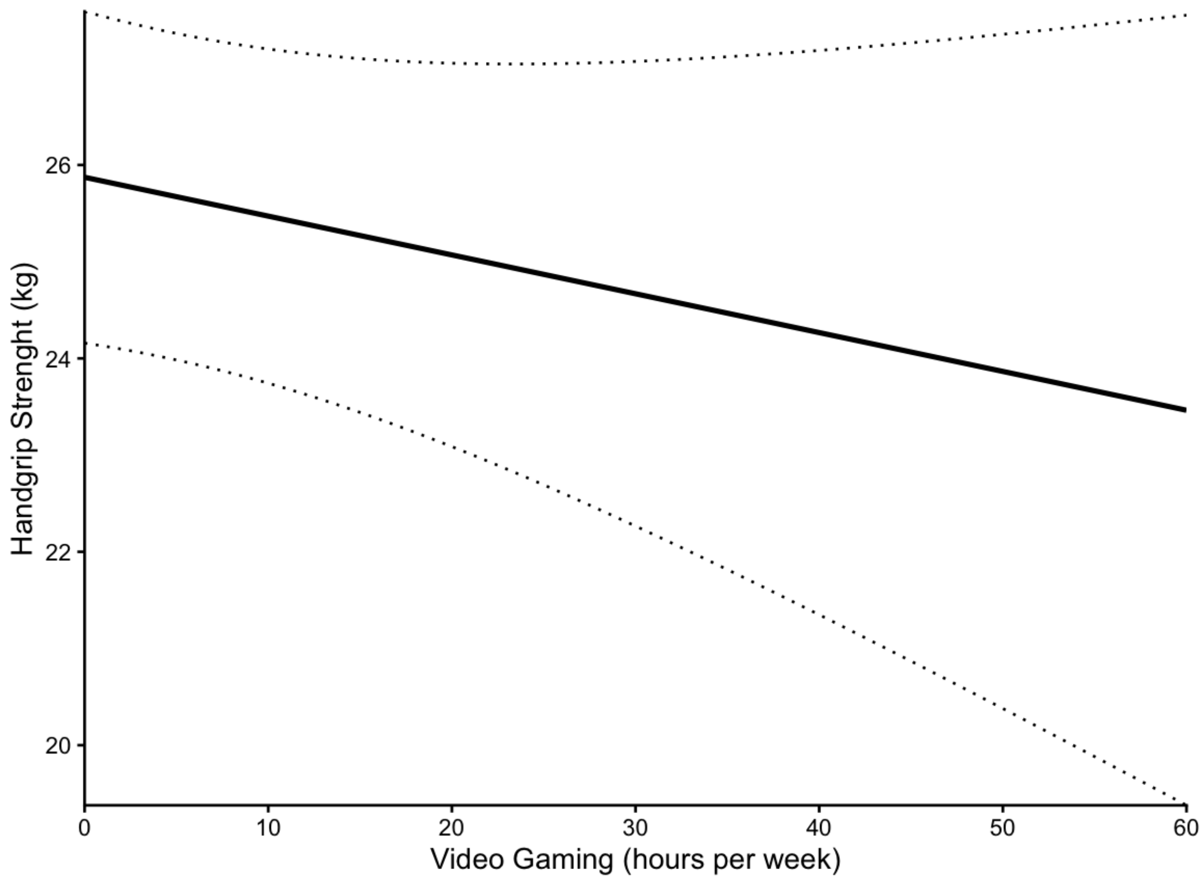

Figure 3.6: Predicted handgrip strength by video gaming hours per week for adolescents (aged 11-18) from generalised additive models with 95% confidence intervals (dotted lines). Video gaming did not significantly contribute to the handgrip strength generalised additive model (p = 0.242).

3.4 Discussion

This study aimed to assess the relationship between VG duration and various cognitive and physiological HRCoF within 180 UK high school, college, and sixth form students. Additionally, generalised additive modelling was implemented to enhance the quality of data analysis across PA, sex and age covariants. Main findings include non-linear relationships between VG duration and coordination, balance, and jump height, PA and age were consistent predictors across several HRCoF, and sex differences were evident in coordination, flexibility, jump height, and handgrip strength. The hypothesis that as weekly VG duration increases, reaction time will become faster was supported.

3.4.1 Reaction Time and Coordination

VG was not a significant predictor of reaction time or coordination within the generalised additive models. Increased weekly VG duration was non-statistically-significantly linearly associated with faster reaction time (EDF = 1), which aligns with the current literature that VGP have faster reaction times than non-VGP and increased VG experience can lead to enhanced reaction times (102,103,143,144). This is most likely due to the repeated exposure to time-sensitive decision-making with up to over 500 actions per minute typically encountered while VG (102,144). Furthermore, PA and age were significant negative predictors of reaction time ($p = 0.004$ and $p < 0.001$, respectively), which could be attributed to developmental enhancements in sensory processing and motor unit recruitment causing faster reaction time (181).

The generalised additive model for coordination indicated a non-linear relationship between weekly VG duration and coordination (EDF = 1.481) and showed an initial non-statistically-significant negative relationship followed by a slightly positive shift at

41.31 h/week. This indicates that initially as weekly VG duration increases, coordination decreases until 41.31 h/week of VG, when coordination begins to slightly increase. This initial non-statistically-significant negative VG-coordination relationship could be due to the prolonged sedentary exposure reducing the opportunity for whole-body motor learning and motor skill refinement, which PA is needed for (182). This is supported within the literature from studies such as Logan et al. (182) which identified through systematic review that object control skills and locomotor skills are strongly related to PA within adolescents. The World Health Organisation recommends that adolescents do on average 60 minutes per day of moderate- to vigorous-intensity PA, however the mean weekly PA was 3.70 $\pm$ 2.05 hours, representing just over half of the recommended weekly duration (183). Therefore, more PA and less VG is required to improve coordination within adolescents, though as previously mentioned, see 3.3.2, no linear piecewise regression breakpoints were identified, hence exact weekly VG hours cannot be determined for this. Moreover, PA was a significant positive predictor of coordination ($p < 0.001$), which could be the cause for the change in VG-coordination relationship.

Males had significantly greater coordination than females, 23.59 $\pm$ 6.87 and 19.71 $\pm$ 8.08 ($p = 0.002$), which are categorised as average and fair, respectively, compared to normative data (184). This could reflect increased engagement in object-control activities during development, enhancing visuomotor integration (185). These coordination scores are greater than current literature demonstrating adolescent male and female coordination as fair, 17.7 $\pm$ 4.8 and 18.8 $\pm$ 5.8, respectively (186). Additionally, this study's adolescent reaction time does align with current literature that adolescent habitual-VGP have faster reaction times than non-VGP (187). However, previous literature does demonstrate that adolescent habitual-VGP have significantly slower reaction times than those who partake in PA, though this previous literature found no difference between those who partake in both PA and VG to those who partake in only one activity, which demonstrates the importance of PA upon cognitive HRCoF (188).

3.4.2 Balance and Flexibility

The results from this study showed that VG time was not a significant predictor of balance ($p = 0.233$). The generalised additive model for balance indicated a non-linear relationship between weekly VG duration and balance (EDF = 1.536) and showed an initial non-statistically-significant negative relationship followed by a positive shift at 32.86 h/week. This indicates that initially as weekly VG duration increases, balance decreases until 32.86 h/week of VG, when balance begins to increase. With VG being a seated sedentary activity it is unlikely this relationship change is due to prolonged VG duration since it was not a significant predictor, instead it is more likely due to PA and age being significant positive predictors of balance ($p = 0.001$ and $p = 0.016$, respectively), see Table 3.3. This reflects the role of movement and developmental progression improving the integration of the vestibular and neuromuscular systems during adolescence (189). Therefore, an increase in PA and decrease in VG would be beneficial at improving balance, however an exact amount of weekly VG hours cannot be stated when someone should stop VG because no linear piecewise regression breakpoints were identified. Furthermore, the absence of a linear association further support the value of GAM, due to linear approaches overlooking relationship change effects associated with excessive VG.

VG was a significant predictor of flexibility ($p = 0.004$) and increased weekly VG duration was linearly associated with reduced flexibility (EDF = 1), which suggests that prolonged VG duration reduces flexibility, this may limit joint range of motion through sustained seated positions and reduced movement variability. This means habitual-VGP with extended weekly VG time have decreased mobility and could therefore be less able to partake in PA, which is known for its associations with negative health implications (155-160), suggesting the importance of reduced weekly VG time. Though due to the linear relationship, the exact hours per week someone should stop engaging in VG cannot be stated. PA and age were significant positive predictors of flexibility ($p = 0.013$ and $p = 0.009$, respectively), see Table 3.3, reflecting that regular PA can enhance flexibility, which in turn can suggest an improvement in muscular elasticity and the neuromuscular maturation during adolescence (190,191).

This study identified adolescent balance in males and females as 4.90 $\pm$ 2.79 and 5.60 $\pm$ 4.58 s respectively, which is categorised as poor when using the Johnson and Nelson (1979) normative scale (192). These scores are lower than the results showed by Fahrosi et al. (193), presenting adolescent footballers balance scores of 10.5 $\pm$ 3.7s. This suggests the importance of PA on balance, which is consistent with the finding that PA was a significant positive predictor of balance ($p = 0.001$), see Table 3.3. Additionally, females had significantly greater flexibility than males, 20.47 $\pm$ 8.69 and 12.39 $\pm$ 6.84 cm ($p < 0.001$), respectively, though both are categorised as good compared to normative data (194). This is consistent with the current literature that adolescent females have greater flexibility than males, 25.9 $\pm$ 7.4 and 19.9 $\pm$ 7.7 cm, respectively (195). This significant difference between females and males is likely due to differences in pelvic structure, connective tissue compliance, and earlier maturation in females, which could influence joint laxity and soft-tissue elasticity (196). This could explain why age was a significant positive predictor of flexibility ($p = 0.009$). Therefore, this shows that multiple factors can influence balance and flexibility, and hence there should be a balance between weekly VG duration and PA.

3.4.3 Jump Height and Handgrip Strength

VG was not a significant predictor of handgrip strength or jump height within the generalised additive models ($p = 0.242$ and $p = 0.539$, respectively). The generalised additive model for jump height indicated a non-linear relationship between weekly VG duration and jump height (EDF = 1.484) and showed an initial non-statistically-significant negative relationship followed by a positive shift at 28.04 h/week. This indicates that initially as weekly VG duration increases, jump height decreases until 28.04 h/week of VG, when jump height begins to increase. This initial non-statistically-significant negative VG-jump height relationship could be due to a lack of movement, which is essential for neuromuscular power development, while VG, and prolonged sedentary exposure causing muscle-tendon stiffness and reduced motor unit recruitment efficiency (197). Neuromuscular power is explosive force production occurring during high-velocity movements, therefore dynamic movements are the mechanism through which power is developed and expressed (197,198). Hence, activities such as resistance training, sprinting and jumping drive adaptations in muscle activation, motor unit recruitment and muscle-tendon properties that underpin power production (197,199). Therefore, the sedentary exposure of VG would not produce these physiological adaptations required for neuromuscular power development and hence VG participation should be in smaller weekly doses. However, due to no linear piecewise regression breakpoints being identified, the exact weekly hours for this cannot be stated. Additionally, age was a significant positive predictor of jump height ($p < 0.001$), which could explain the change to a positive relationship, due to increased muscle mass and neuromuscular coordination development through adolescence (200).

Increased weekly VG duration was non-statistically-significantly linearly associated with reduced handgrip strength (EDF = 1), which could be due to prolonged VG duration causing neck stiffness leading to a weakness in the shoulders and upper body muscles (201). Additionally, this could cause negative affects on bone mass, since bone mass response is at its highest throughout adolescence when the skeletal tissue is most susceptible to mechanical loading (201). For good bone and muscle mass formation, PA is imperative, which does not occur while engaging in sedentary VG (201). Hence, PA should be encouraged while reducing weekly VG duration, however it cannot be exactly stated when someone should stop VG due to the linear relationship found. Therefore, the absence of a non-linear VG-handgrip strength relationship and this decrease in handgrip strength, suggests that general strength development during adolescence is more strongly driven by biological maturation than VG behaviours, which is proven as age was a significant positive predictor of handgrip strength ($p < 0.001$).

Males had significantly greater jump height and handgrip strength than females, 37.12 $\pm$ 8.03 to 34.45 $\pm$ 7.59 cm ($p = 0.033$) and 27.00 $\pm$ 7.19 to 24.63 $\pm$ 5.41 kg ($p = 0.008$), respectively. Compared to normative data jump height is categorised as below average in males and females (202) and handgrip strength is categorised as very poor in males although below average in females (203). This aligns with current literature presenting significant increases in jump height and handgrip strength in adolescent males to females, 28.3 $\pm$ 8.0 to 21.5 $\pm$ 5.9 cm and 36.8 $\pm$ 9.4 to 26.1 $\pm$ 4.8 kg, respectively (195). This significant difference is likely due to increases in male testosterone levels during adolescence, causing an increase in lean muscle mass enhancing power output and force production (204,205). This is supported within the literature from studies such as Xu et al. (204) and Ramos et al. (205) that show testosterone increases within this age group and the link it has between muscle mass and strength. Additionally, it has also been found within the literature that adolescent habitual-VGP have significantly reduced handgrip strength than non-VGP, which is consistent with the negative linear VG-handgrip strength relationship found (201).

To the authors knowledge, this is the first study to identify the relationships between weekly VG duration and a comprehensive range of HRCoF within adolescents, which begins to address the literature gap outlined in Chapter 2. Inclusion of physiological and cognitive HRCoF provides a more holistic assessment compared to previous research, which has typically focussed on isolated outcomes, as outlined in chapter 2. The use generalised additive modelling analysis to predict these relationships within adolescents allows for the identification of non-linear relationship that would be not be detectable using traditional linear approaches and avoids the oversimplification of complex behavioural relationships. Additionally, the relatively large sample size (n = 180) enhances the statistical power of the analyses and improves generalisability of the findings.

3.4.4 Practical Implications

VG has non-statistically-significant negative associations with four HRCoF and significant negative associations with one HRCoF, it is therefore imperative to monitor and reduce adolescent excessive VG and encourage PA regardless of VG habits. However, due to no linear piecewise regression breakpoints being identified and the linearity of relationships, it is not possible to establish precise weekly VG duration recommendations. Muscular strength and power are associated with skeletal health and reduced risk to cardio-metabolic health (152,154), and the current study found these decrease with adolescent VG duration, calling concern to these individuals health who engage in excessive weekly VG. Reduced flexibility was significantly associated with excessive weekly VG, calling to question the likeliness of an individual with reduced mobility to partake in PA to offset the negative implications of prolonged weekly VG. On the other hand, VG has positive implications upon reaction time, which is associated with other cognitive benefits, for example executive function and processing speeds (83,84). Therefore, there should be a balance between weekly VG and PA; adolescents should be encouraged to reduce their weekly VG duration, without eliminating it entirely, and participate in PA regardless of VG habits.

3.4.5 Limitations and Future Recommendations

There are some limitations to this study, increasing the sample size would enhance the strength and robustness of the generalised additive models, as larger samples improve statistical power and allow for more reliable detection of non-linear relationship that generalised additive models are specifically designed to capture. Lab-based testing could be more reliable than field-based HRCoF testing, as controlled environments minimise external variability (e.g., participant distractions), thereby improving measurement accuracy. Only adolescent non-VGP and habitual-VGP were included, which limits the generalisability of the findings to other populations. Additionally, maturation and pubertal status was not measured or taken into account, which would allow for more specific interpretations in relation to age. Furthermore, this is an observational study so causal pathways have limited interpretation.

Therefore, future research should focus on comprehensive HRCoF testing in a wider range of aged habitual-VGP with large sample sizes, to improve external validity and enable more nuanced subgroup analyses across developmental stages and VG behaviours. Studies including adolescents should include maturation and pubertal staging, to better account for biological variability and isolate the independent effects of VG exposure. Finally, longitudinal studies are needed to examine the causal pathways between HRCoF, PA and age, to weekly VG duration, as repeated-measures designs would allow researchers to track changes over time, establish temporal sequencing, and better infer causality between sedentary VG behaviours and HRCoF.

3.4.6 Conclusions

Reaction time was the only health-related component of fitness positively associated with weekly VG duration, which is consistent with previous literature. Flexibility, balance, handgrip strength, jump height and coordination were all negatively associated with weekly VG duration, though the association with flexibility was the only statistically significant VG association, however were all positively statistically significantly influenced by PA or age. Therefore, a reduction of excessive weekly VG time and a balance between weekly VG use and PA is recommended within adolescents. Future research should focus on wider comprehensive HRCoF testing in various aged VGP and longitudinal studies.

Chapter 4: Discussion

The overall aim of this research project was to investigate the relationship between video gaming (VG) and physiological and cognitive health-related components of fitness (HRCoF). The global growth of VG within adults and adolescents, causes an increased sedentary lifestyle and hence public health concerns (10-14,17). The health and fitness of the general population is immensely important, therefore it is imperative to understand the implications VG can have upon HRCoF levels. Chapter 2 used systematic review to collate and synthesise the current literature on the implications of VG across HRCoF, which found adult male-dominated research focussing on reaction time, with one study including strength and flexibility. Hence Chapter 3 aimed to assess the relationships between VG duration and various HRCoF, including physiological (handgrip strength, flexibility, balance and jump height) and cognitive HRCoF (reaction time (RT) and coordination), within adolescents, a key time in development (152). Subsequently using generalised additive modelling (GAM) to predict these relationships. Chapter 3 identified reaction time to be positively associated with VG duration, while handgrip strength, flexibility, balance, jump height and coordination were negatively associated with VG duration within adolescents.

4.1 Video Gaming and Physiological Health-Related Components of Fitness

The relationship between VG and physiological HRCoF appears slightly unclear and remains under-explored within existing literature. Chapter 2 identified only one study that assessed any physiological HRCoF in video gaming players (VGP), which reported greater shoulder flexibility, although decreased shoulder strength in habitual-VGP compared to non-VGP (143). These findings suggested that prolonged VG could contribute to musculoskeletal adaptations due to the maintained seated posture and repetitive upper-limb activity, potentially causing muscle imbalances (143). Therefore, it was important to include various physiological HRCoF within Chapter 3 to get a wider understanding of VGP physiological HRCoF levels, due to the differences identified in Chapter 2. Similarly, within adolescents, greater weekly VG time was associated with decreased handgrip strength, though contrastingly decreased flexibility. Additionally, balance and jump height were also decreased, although these associations were often non-linear and were significantly influenced by other factors, for example physical activity (PA) and age. Taken together, the findings from both studies indicate that while VG may not directly determine physiological HRCoF, excessive engagement in sedentary VG could contribute to reduced physiological HRCoF if not balanced with sufficient PA.

Prolonged engagement in VG can have implications upon physiological HRCoF outcomes and musculoskeletal health due to the sedentary nature of VG. Accumulating high levels of sedentary behaviour has been associated with negative health outcomes, including reduced muscular fitness, poorer metabolic health, and increased cardio-metabolic risk (10). The sustained seated posture and repetitive upper-limb movements during VG, can contribute to altered muscle activation patterns and postural imbalances (19). Additionally, prolonged sedentary VG could contribute to reduced opportunities for musculoskeletal development during key growth periods within adolescents (206). This reduced mechanical loading of the musculoskeletal system can also inhibit bone mineralisation, muscular strength development, and joint mobility (207). This aligns with the findings within Chapter 2, the imbalances in shoulder muscle strength and flexibility, and Chapter 3, greater weekly VG duration is associated with reduced handgrip strength and flexibility within adolescents. However, PA was a key positive predictor across multiple HRCoF, suggesting that potential physical health implications of VG could be largely influenced by how much sedentary VG displaces time spent engaging in PA.

PA appears to play a central role in moderating the relationship between VG duration and HRCoF. Regular participation in PA has consistently been associated with improvements in physiological HRCoF, including muscular strength, power, flexibility and balance (152,208). Particularly within adolescents, movement-based activities provide essential mechanical loading and neuromuscular stimulation that support skeletal development, muscular adaptation and motor skill acquisition (209). Consequently, when sedentary behaviour, such as prolonged VG, replaces time that could be otherwise spent engaging in PA, negative physiological HRCoF outcomes may occur. The findings of the present thesis suggest that PA could act as a protective factor against these potential effects. This aligns with broader literature demonstrating that adolescents who engage in higher levels of PA typically exhibit superior physiological HRCoF compared with less active peers (152). However, there is no current literature presenting PA to moderate the VG-HRCoF relationships, thus could be a direction of future research. Therefore, instead of VG determining physiological HRCoF outcomes alone, the balance between VG time and PA participation is an important determinant of overall physiological HRCoF.

4.2 Video Gaming and Cognitive Health-Related Components of Fitness

Across both studies within this research project, reaction time emerged as the HRCoF most consistently positively associated with VG, suggesting a potential cognitive-performance adaptation linked to VG exposure. Chapter 2 demonstrated that RT was faster in habitual-VGP and electronic sport athletes (E-athletes) compared to non-VGP (102,143), elite or high-skilled compared to lower-skilled E-athletes (103,144), and first person shooter compared to multiplayer online battle arena habitual-VGP (78). Hence identifying RT as an important HRCoF in regards to VG, and it being a key HRCoF to include in Chapter 3, which similarly demonstrated a positive association between weekly VG time and RT within adolescents, where faster reaction time was associated with greater weekly VG time, which supported the hypothesis. This is consistent with Chapter 2's findings, specifically the findings by Guney et al. (143), which identified faster RT within habitual-VGP than non-VGP, as well as the findings of Luu et al. (102), Ersin et al. (103), and Toth et al. (144), though these were within E-athletes not habitual-VGP. However, other cognitive HRCoF, such as coordination, as seen in Chapter 2 are not covered in current literature, therefore it was important to include coordination within Chapter 3, although it found coordination to decrease with greater weekly VG time.

These findings on cognitive HRCoF are consistent (reaction time) and inconsistent (coordination), with current literature on various other cognitive benefits of VG. Repeated exposure to the rapid and visually complex environments of many VG has been suggested to promote cognitive adaptations, specifically within perceptual-motor processing and attention systems. VG often require VGP to process multiple visual stimuli simultaneously, making rapid decisions, and execute precise motor responses under time pressure. The repeated exposure to this has been associated with improvements in visuospatial attention, perceptual processing speed and cognitive flexibility (210,211). Neuro-cognitive research has suggested that these adaptations could occur through experience-dependent neuroplasticity, where repeated task demands strengthen neural pathways associated with visual attention and sensorimotor coordination (212). Faster reaction times observed amongst VGP are therefore likely reflective of faster information processing and enhanced perceptual-motor integration rather than purely faster motor execution. Therefore, the findings from Chapter 2 and 3 regarding faster reaction times is consistent with current literature examining the cognitive benefits of VG. Whereas, the findings from Chapter 3 regarding decreased coordination are inconsistent with this current literature. However, these studies differed from Chapter 3 due to including male only adults aged 18 to 26 years old (210,212). Additionally, action genre VGP have exhibited superior visual selective attention and improved ability to track multiple moving objects compared with non-VGP, suggesting that VG experience may enhance the efficacy of attentional resource allocation and hence allow for these faster reaction times seen in VGP (210). However, the observational nature of the existing literature and the present study prevent causal interpretations.

4.3 Video Gaming and Population and Exposure Differences

Developmental and population differences also appear to play an important role in the relationships between VG and HRCoF. Chapter 2 identified six studies with all adult populations, predominantly focussing on male-only samples, and habitual-VGP or E-athletes. Limited representation of females was present within two studies; mixed-sex sample and female only sample (142,143). Therefore, Chapter 3 broadened the scope of populations being included within VG and HRCoF research by examining a large adolescent cohort of males and females, allowing for the exploration of sex-related differences within HRCoF. Significant sex differences were identified; females demonstrated greater flexibility and males demonstrated greater handgrip strength, jump height and coordination. Additionally, age was a significant positive predictor among all six HRCoF tested. These findings are consistent with well-established developmental patterns during adolescence, where differences in biological maturation, hormone influences and musculoskeletal development contribute to divergent physiological HRCoF trajectories between males and females and increasing age (200,213). The inclusion of an adolescent population within this thesis extends the current literature and therefore highlights the interaction between VG duration and HRCoF may differ across developmental stages. Collectively, these findings emphasise the importance of considering demographic characteristics, such as sex and age when interpreting the physiological and cognitive fitness implications of VG participation.

In addition to demographic characteristic, the role of VG exposure and “dose” is important to consider when examining the relationships between VG and HRCoF. Chapter 2 identified that greater VG experience and skill level are associated with significantly faster RT (103,144). Additionally, first person shooter VGP had significantly faster reaction times than multiplayer online battle arena VGP, suggesting the influence of VG exposure upon cognitive HRCoF could be due to different genre-specific characteristics (78). Therefore, Chapter 3 extends these findings by using generalised additive modelling, which identified the relationship between VG duration and several HRCoF is not strictly linear. Non-linear associations were identified between weekly VG duration and balance, jump height and coordination, with positive changes in the direction of these relationships occurring at higher weekly VG durations. Collectively, these results indicate that the influence of VG on physiological and cognitive HRCoF are likely dose-dependent and influenced by factors such as VG experience and duration, reinforcing the need to consider VG behaviours within a broader behavioural context rather than treating VG exposure as a uniform activity.

The non-linear relationships observed between VG duration and balance, jump height and coordination, may be interpreted in the context of underlying developmental and sex-related influences rather than VG behaviour alone. As previously mentioned in Chapter 3, age is a positive predictor for these three HRCoF, which aligns with current literature characterising adolescence as having rapid non-linear changes within neuromuscular performance, which are driven by growth, maturation and hormonal changes, substantially influencing fitness outcomes independent of behavioural exposures (200). In particular, increases in muscular power and motor coordination are closely linked to maturation-related developments in muscle architecture and neural activation, which do not occur in a strictly linear fashion across adolescence (214). Similarly, balance performance can improve with age as a result of maturation of the sensory systems, including vestibular, visual and proprioceptive integration, which underpin postural control (215). Additionally, the significant difference in jump height and coordination between males and females, could be attributed to difference in neuromuscular development, particularly the influence of increased testosterone levels within males, contributing to divergent trajectories within strength and power development (213). These developmental processes occur alongside, and often overshadow, lifestyle behaviours such as VG, particularly within adolescent populations. This shows that both females and males must be included within VG relationship with HRCoF research, which was lacking within the current literature identified within Chapter 2, and that different sexes and ages should be assessed independently. Therefore, the observed non-linear patterns are likely reflective of these complex, interacting developmental trajectories, where age and sex act as primary drivers of change in fitness, rather than direct effects of VG exposure itself.

Although sex and age can account for the relationship between VG and various HRCoF, differing VG exposures could explain the relationships between VG and cognitive HRCoF. Action-oriented VG genres, such as first person shooter, typically require rapid visuomotor responses and continuous monitoring of dynamic visual stimuli, whereas strategy-based VG genres, such as multiplayer online battle arena, require planning and strategic decision making over rapid motor responses (216). Hence, these differing task demands have been shown to produce different cognitive adaptations, for example action genre VG showing stronger associations to reaction time and processing speeds than strategy-based VG (217). However, Chapter 3 did not compare across VG genres, as such these comparisons between genres cannot be made in relation to adolescents, and should be considered for future research. Additionally, alongside the task specificity of differing VG genres, duration of VG could reflect the development of expertise through repeated practice, a process consistent with broader theories of skill acquisition, where repeated task exposure enhances skill level (218). However, an alternative explanation for this faster reaction time within more experienced and higher skill level VGP is self-selection. This is where individuals with naturally superior cognitive abilities may be more likely to engage or excel within VG environments. It has been suggested that both mechanisms happen simultaneously, with VG providing the opportunity for individuals with naturally enhanced cognitive abilities to further improve their cognitive skills (217). These mechanisms could be explored more extensively in future longitudinal research. Hence, the observed relationships between VG and HRCoF, supports the idea that these fitness outcomes are unlikely to be explained by a single mechanism. Instead, the impact of VG on physiological and cognitive HRCoF is likely to be shaped by a combination of individual differences, for example age and cognitive abilities, exposure dose and task specificity.

Therefore, this thesis has addressed the current aims through a mixed-method approach. Chapter 2 collated and synthesised existing literature regarding the fitness levels of VGP, and Chapter 3 addressed the gaps found within the literature by empirically assessing a wide range of physiological and cognitive HRCoF within adolescents, using generalised additive modelling analysis. By doing so, this thesis has extended the current literature by clarifying what is currently known regarding VG and HRCoF levels; faster reaction times. Subsequently, extended this further by addressing evidence gaps (e.g., adolescents and females) and employing generalised additive modelling, allows for the identification of non-linear relationships and avoids oversimplification of complex behavioural relationships, to identify the nature of VG's associations with various HRCoFs; decreased flexibility, balance, handgrip strength, jump height, and coordination. Additionally, this thesis has identified key areas for future research. This is important to understand because these outcomes have been linked to negative health implications, such as increased all-cause and cancer mortality and risk of stroke, and hence it is important to provide critical information to the general population regarding their lifestyle choices upon their health (85-89).

4.4 Practical Implications

The findings of this thesis highlight several practical implications for public health, education and youth lifestyle, particularly regarding the balance between sedentary VG and PA. Given the widespread engagement in VG among adolescents, it is important that VG is not viewed solely as a harmful behaviour but rather considered within the broader context of daily PA and health behaviours. The findings of this thesis demonstrate that greater weekly VG duration is associated with enhanced cognitive HRCoF though a reduction in several physiological HRCoF, while PA was a consistent positive predictor of these HRCoF. Building on these findings, there is a clear need for interventions that do not simply aim to reduce VG participation, but instead promote behavioural regulation and time management strategies among adolescents. Such approaches may be more realistic and sustainable given the cultural and social integration of VG within this population. Therefore, promotion of a balanced lifestyle in which VG can coexist with regular PA rather than completely discouraging VG is recommended. From a public health perspective, these findings support the development of guidelines that emphasise both the reduction of prolonged sedentary behaviour and the accumulation of sufficient levels of moderate-to-vigorous PA. Importantly, interventions should focus on displacement effects, whereby excessive VG time may replace opportunities for PA, sleep, or other beneficial health behaviours.

Parents, educators and policy makers should encourage a reduction in weekly VG duration alongside structured opportunities for movement throughout the day, for example regular breaks during prolonged VG sessions, and participation in organised sport or recreational PA to offset sedentary VG duration. In educational settings, schools may play a pivotal role by integrating movement-based breaks within the school day and promoting extracurricular PA programmes that appeal to a wide range of interests and abilities. Additionally, incorporating education around healthy screen use and self-regulation strategies into the curriculum may further support adolescents in developing balanced lifestyle habits. At the family level, parental modelling of active behaviours and the establishment of household norms around screen time may further reinforce positive behavioural patterns. For example, implementing screen-time limits, encouraging active alternatives, and promoting family-based physical activities may help mitigate the negative associations observed between VG duration and HRCoF. Collectively, these findings highlight the importance of a holistic and multi-level approach, involving individual, familial, educational, and policy-level strategies, to effectively support adolescents in achieving a balanced integration of VG and PA within their daily lives.

4.5 Limitations and Future Recommendations

The main limitations of this thesis include methodological constraints within Chapter 3, for example, an increased sample size would enhance the statistical power and generalisability of the findings, thereby improving the strength and robustness of the generalised additive models. Lab-based testing could be favourable over field-based testing, as it allows for greater control of measurement precision, although this may come at the expense of ecological validity. Maturation was not measured, which is a notable limitation given its potential influence on both physical and cognitive development within adolescents, and may therefore confound the observed relationships.

In addition, the female and male sample split was not equal, potentially causing biases, as sex-based physiological and behavioural differences may influence both VG engagement and HRCoF, limiting the generalisability of the findings across populations. The cross-sectional observational nature limits causal pathway interpretations, as it prevents the determination of directionality between VG and HRCoF, making it unclear whether observed relationships reflect cause, consequence, or bidirectional relationships. Furthermore, moderation analysis of PA, age and sex to the VG-HRCoF relationships was not included, which represents a missed opportunity to explore potential interaction effects and underlying mechanisms. Including such analyses could provide deeper insight into whether these relationship vary across demographic or behaviours subgroups.

Therefore, as discussed previously within Chapter 2, future research should continue to widen the scope of physiological and cognitive HRCoF testing within VGP, including equal samples of males and females and across a range of ages. This would enhance the external validity of findings and allow for more nuanced subgroup analyses. Findings from Chapter 3 advances understanding within this area, however, they also highlighted several areas requiring methodological refinement, including improved measurement approaches, for example, neuromuscular and musculoskeletal assessments, and neurocognitive and executive function outcomes. Incorporating more sensitive and multidimensional assessment tools may allow researchers to capture subtle adaptations associated with VG behaviours.

As discussed within this chapter, future study design should focus on longitudinal and intervention studies to provide causal pathway interpretations, for example skill-acquisition vs self-selection mechanism longitudinal studies. Longitudinal designs would enhance tracking of changes over time, while intervention studies could help establish whether VG directly influence HRCoF or whether pre-existing characteristics drive engagement. Furthermore, including moderation analysis of various factors influencing the VG-HRCoF relationships, would allow for more specific interpretations of, for example, PA's affect upon these relationships. Such approaches would contribute to a more comprehensive and theoretically grounded understanding of how and for whom VG may impact physiological and cognitive HRCoF outcomes.

4.6 Conclusions

Overall, this thesis provides evidence that engaging in VG is associated with faster reaction times within adult habitual VGP and E-sport athletes, and adolescent habitual VGP. Although, VG is associated with decreased HRCoF, including balance, handgrip strength, flexibility, jump height and coordination within adolescents. Therefore, this thesis provides recommendations for parents, educators and policy makers to encourage a balance between VG participation and PA, and regular breaks during prolonged VG sessions, to offset sedentary VG duration. Future research should prioritise longitudinal or intervention studies including lab-based assessments of HRCoF within female and male VGP.

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Appendix

Appendix 1 – Newcastle-Ottawa Scale Scores

Article	S 1	S 2	S 3	S 4	C A	C B	O 1	O 2	Total Stars	Quality Rating
Shoot at first sight! First person shooter players display reduced reaction time and compromised inhibitory control in comparison to other video game players https://www.scopus.com/inward/record.uri?eid=2-s2.0-85015702150&doi=10.1016%2fj.chb.2017.02.027&partnerID=40&md5=7594b3a070ec0b3c06001b6407d7e00d	1	1	0	1	1	1	1	1	7	High
Searching in clutter: Visual behaviour and performance of expert action video game players https://www.scopus.com/inward/record.uri?eid=2-s2.0-85117921651&doi=10.1016%2fj.apergo.2021.103628&partnerID=40&md5=6f3735fc25d5c4a8581bce35cff2de5c	1	1	1	1	0	1	1	1	7	High
Screen-based sedentary behaviour and associations with functional strength in 6-15-year-old children in the United States https://pubmed.ncbi.nlm.nih.gov/26846277/	1	1	1	1	0	1	1	0	6	Fair
The relationship between reaction time and gaming in e-sports players https://www.scopus.com/inward/record.uri?eid=2-s2.0-85130260789&doi=10.26582%2fk.54.1.4&partnerID=40&md5=d4112b2d42b905523531c9d3ba7ace22	1	1	1	1	1	1	1	1	8	High
Investigation of the playing digital games on shoulder flexibility, muscle strength and reaction speed in volleyball players https://pubmed.ncbi.nlm.nih.gov/39559379/	1	1	0	1	1	1	1	1	7	High
Differences in eye-hand motor coordination of video-game users and non-users https://pubmed.ncbi.nlm.nih.gov/6622153/	1	1	0	1	0	1	0	1	5	Fair
The effects of regular physical activity and playing video games on reaction time in adolescents	1	1	0	1	0	1	1	0	5	Fair

https://search.ebscohost.com/login.aspx?direct=true&db=mdl&AN=35954637&site=ehost-live&scope=site&authtype=sso&custid=s9814295										
Reaction times for esport competitors and traditional physical athletes are faster than noncompetitive peers https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105349387&doi=10.18061%2fojs.v121i2.7677&partnerID=40&md5=5bcbeab63950d3af5960036c0a22c295	1	1	1	1	1	1	1	1	8	High
Action video games improve direction discrimination of parafoveal translational global motion but not reaction times https://www.scopus.com/inward/record.uri?eid=2-s2.0-84988353450&doi=10.1177%2f0301006616663215&partnerID=40&md5=7f71d1e19a28c5fe07df5053c05444a9	1	1	1	1	0	1	0	1	6	Fair
The colour-word strop task does not differentiate cognitive inhibition ability among esports gamers of varying expertise https://www.scopus.com/inward/record.uri?eid=2-s2.0-85077437439&doi=10.3389%2ffpsyg.2019.02852&partnerID=40&md5=5f9716df1e9c679511e347663fd8b0a0	1	1	1	1	1	1	1	0	7	High

Note. S selection, C comparability, O outcome.

Appendix 2 – Parental Consent Form (Qualtrics Version)

MSD PIS, Consent and PAR-Q - TGS

Start of Block: Participant Information Sheet

Participant Information Sheet Project title: Relationships Between Video Gaming and Fitness Components in Adolescents Invitation paragraph My name is Bethany Thompson and I am a Masters research student in the School of Sport, Rehabilitation and Exercise Science (SRES) at the University of Essex. I would like to invite you to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it involves. Please take the time to read the following information carefully and please ask anyone within the research team if there is anything that is not clear or if you would like more information. What is the purpose of the study? The purpose of this study is to examine if there is an association between video gaming and fitness within adolescence (11-19 years) and the impact video gaming has on these markers of fitness. This study is being completed as part of a Masters by Dissertation research by a student and will run for one year. Why have I been invited to participate? You are invited to take part if you are currently a high school, sixth form or college student, aged 11-19 years, and have no health or medical conditions. We will ask you to complete a short questionnaire before engaging in any activity to answer questions about your current health and medical conditions, to ensure you are eligible to participate. Do I have to take part? If you are 18 years of age and above, it is up to you (consent), and if you are below 18 years of age, it is up to you (assent) and your parent (consent) to decide whether or not you wish to take part in this study. If you do decide to take part, you will be asked to provide consent, if you are 18 years of age and above or both informed consent and assent, if you are below 18 years of age. Parental consent will be obtained through the head of physical education sending an email to all the parents containing a small explanation of the study and a link to the participant information sheet, parental consent form and PAR-Q Qualtrics survey. From the parental consent form, participants name will be added to a register within Excel, which will be given to the head of physical education to assist in organising only participants whose parents/guardians have given consent attend the data collection. Participant assent will be obtained on the day of data collection through a Qualtrics survey containing the participant assent form and questions on their video gaming and physical activity habits, and data collection will happen during students' physical education lessons so not to disrupt their academic learning. Participant names from the assent form will be matched across to the register created from the parental consent forms, to double check they have the correct consent and assent to partake. If a student does happen to attend the data collection who doesn't have parental consent, they will be asked politely to return to their physical education lesson and will not be allowed to partake in the study. You are free to withdraw at any time, without giving a reason. What will happen to me if I take part? The head of physical education at your school will send, by email, your parents/guardians a link to a consent form and physical activity readiness questionnaire. If you are below 18 years old your parent/guardian will have to consent to you taking part, and if you are 18 years old and above you can consent to yourself taking part. You will be required to complete a single testing session at your school/sixth form/college during the school day for 30-45 minutes. During the testing session, the research team, overseen by the lead researcher (Bethany Thompson), will conduct a series of simple fitness measures and personal characteristic measurements, and you will be required to complete a questionnaire regarding your video gaming and exercise habits. This questionnaire will also contain an assent form for the participants under 18 years old. Fitness tests include a handgrip dynamometer test to measure grip strength, a measurement of jump height using force decks to measure anaerobic lower limb power, an alternate-hand wall toss test to measure coordination, a ruler drop test to measure reaction time, a sit and reach test to measure flexibility, and a 'y balance' test to measure balance. Personal characteristic measurements include body mass and height. This data collection will also be supervised by members of staff from the school / sixth form at all times, whom are DBS checked. What information will be collected? We will collect information about your personal characteristics, which include age, body mass, height. Fitness level, such as handgrip strength, maximal jump height, coordination, reaction time, flexibility and balance. Exercise and video gaming habits on a weekly bases through a questionnaire and lifestyle factors and previous injuries through a physical activity readiness questionnaire (PAR-Q). What are the possible benefits of taking part? There are no direct benefits from taking part in this study, but you will help with teaching good research practice. What are the possible disadvantages and risks of taking part? There are no disadvantages of taking part in this study. There are some very small risks associated with physical movements and exercise, such as injury because of tripping, falling, overstretching, and exertion. We'll mitigate these by making sure you are fit, healthy and have no known medical conditions before we begin testing, letting you know that you can stop at any time, asking you to tell us if you feel uncomfortable or unwell at any time and ensuring any equipment has been checked and is used safely. How will my data be stored and who will have access to it? All data will be securely stored on Box, the University of Essex secure online storage platform that is password protected with a two-stage authentication. Only the research team and supervisors will have access to the data. How long will my data be stored for? Your data will be securely kept for a maximum of 10 years after completion of the research study. Within this time the anonymised data file version will be uploaded and shared to the UK data service or equivalent online repository. This file will have no names or personal identifiers associated with it. Will my participation be kept confidential? Your privacy will be respected if you choose to take part in this study. All data will be kept confidential and unique participant numbers will be allocated instead of using your name in any presentation or reporting of the data. Your name will not appear in the database alongside the data / information you provide. Instead, your data will be assigned a unique participant identification code, via a password-secure process involving separate files. To ensure anonymity, participant ID Numbers will be used in a data collection Excel file within Box. Only the researchers will be able to identify data via use of a separate, password-protected 'codebreaker' file that contains participants' names and assigned ID numbers. Only the researchers have access to this. The final database will be anonymous, and participants will never be identified in any way, not their data be identifiable within publications or any other dissemination media. Participants' participation and data will remain confidential at all times and will be treated as confidential by the research team. How will my data be used and in what form will it be shared further? After data collection has been completed, data will be analysed, and results disseminated through presentations and/or publications. All data used in any dissemination will be fully anonymised and you will not be identifiable. The anonymous results of this study may also be used in future to guide further research in this area and may be anonymously shared with other researchers. Please let the research team know if you would like to have a copy of the results of this study. Withdrawing my data Participants can ask for access to the information they provide and can request the destruction of that information if they wish at any time prior to June 2025 following which they will not be able to request access to or withdrawal of the information they have provided. What is the legal basis for using personal data and who is the Data Controller? The University processes personal data for the primary purpose of research under the lawful basis of processing set out in Article 6 (1)(e) of the UK GDPR, ‘processing is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller’. The University’s lawful basis for processing Special Category data is Article 9 (2), (j) ‘processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1)’. Using this lawful basis requires the University to also meet a substantial public interest condition as set out in Schedule 1, Part 1 of the Data Protection Act 2018. The condition that the University will use is 4. Research, etc. Under UK data protection legislation, the University acts as the Data Controller for personal data collected as part of the University’s research. For more information on data protection legislation and your rights visit the University’s Data protection and research activity webpage. For any queries, email dpo@essex.ac.uk. Who has reviewed the study? The project received a favourable ethical opinion by the University of Essex Ethics Committee. What should I do if I want to take part? If you want to partake in the study, please tell your Head of Physical Education and they will send you the physical activity readiness questionnaire, informed consent form, and lifestyle questionnaire to fill out before the arranged testing at your school/sixth form/college. If you have any questions, please contact Bethany Thompson at bt21252@essex.ac.uk. Disclosure Barring Service Check The lead researcher, Bethany Thompson, has obtained a DBS check and you can request evidence of this. The research will also be supervised by members of staff from the school / sixth form at all times. Concerns and Complaints If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the research team Bethany Thompson, Dr Henry Chung, and Dr Mike Rogerson, using the contact details below. If you are still concerned, if you think your complaint has not been addressed to your satisfaction or you feel that you cannot approach the principal investigator, please contact either the Head of SRES Postgraduate Research Degrees, Dr Matt Taylor (mtaylor@essex.ac.uk), or the School Director of Research responsible for this project, Dr Jamie Tallent, (jamie.tallent@essex.ac.uk). If you are still not satisfied, please contact the University of Essex REO Research Integrity Manager (reo-integrity@essex.ac.uk). Please include the ERAMS reference which can be found at the footer of this page so that the study can be identified, details of the name or description of the study, the researcher(s) involved, and the details of the complaint you wish to make. Contact details Bethany Thompson (student): bt21252@essex.ac.uk Henry Chung (supervisor/lecturer): henry.chung@essex.ac.uk Mike Rogerson (supervisor/senior lecturer): mike.rogerson@essex.ac.uk Version: 2 Date: 06/11/2024 ERAMS: ETH2425-0392

End of Block: Participant Information Sheet

Start of Block: Consent

Consent If your child is under the age of 18 years old, you will need to consent on their behalf for them to take part in this study. If your child is 18 years old or above, they can give consent to partake in this study themselves and therefore should now complete these questions. Are you consent on behalf of your child or is your child now consenting for themselves to take part in this study?

◯ Child is over 18 and will now complete this questionnaire themselves (1)

◯ Child is under 18 and I will complete this on their behalf (2)

End of Block: Consent

Start of Block: Participant Consent Form

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Participant Consent Form Research Team: Bethany Thompson, Dr Henry Chung and Dr Mike Rogerson Consent form v3: 06/11/2024 ERAMS reference: ETH2425-0392

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 1 - I confirm that I have read and understood the Participant Information Sheet Dated 06/11/2024 for the above study. I have had an opportunity to consider the information, ask questions and have has these questions answered satisfactorily.

◯ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 2 - I understand that my participation is voluntary and that I am free to withdraw from the project at any time without giving any reason and without penalty. I understand that any data collected up to the point of anonymisation will be destroyed if i withdraw. If I withdraw after data have been anonymised, researchers will be unable to identify and remove my data.

◯ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 3 - I understand that the interventions used in this study might require some physical movement or activity and may not be suitable for participants with health or medical conditions. I confirm that I am uninjured and have no health or medical conditions that would prevent me from participating in this study.

○ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 4 - I understand that the identifiable data provided will be securely stored and accessible only to members of the research team directly involved in the project, and that confidentiality will be maintained.

○ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 5 - I understand that the data collected about me will be used to support other research in the future and may be shared anonymously with other researchers.

○ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 6 - I understand that that the anonymised data collected about me will be uploaded and shared to the UK data service or equivalent online repository.

○ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Statement 7 - I agree to take part in the above study.

○ Agree (1)

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Participant Full Name, as registered with your school

____

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Date

____

Display this question:

If Consent = Child is over 18 and will now complete this questionnaire themselves

Participant Consent Participant Signature

End of Block: Participant Consent Form

Start of Block: Parental Consent Form

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Parental Consent Form Research Team: Bethany Thompson, Dr Henry Chung and Dr Mike Rogerson Consent form v1: 06/11/2024 ERAMS reference: ETH2425-0392

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Your Child’s Full Name, as registered with their school

____

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 1 - I confirm that I have read and understood the Participant Information Sheet Dated 06/11/2024 for the above study. I have had an opportunity to consider the information, ask questions and have has these questions answered satisfactorily.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 2 - I understand that my child's participation is voluntary and that they are free to withdraw from the project at any time without giving any reason and without penalty. I understand that any data collected up to the point anonymisation will be destroyed if they withdraw. If they withdraw after data have been anonymised, researchers will be unable to identify and remove my data.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 3 - I understand that the interventions used in this study might require some physical movement or activity and may not be suitable for participants with health or medical conditions. I confirm that my child is uninjured and has no health or medical conditions that would prevent them from participating in this study.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 4 - I understand that the identifiable data provided will be securely stored and accessible only to members of the research team directly involved in the project, and that confidentiality will be maintained.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 5 - I understand that the data collected about my child will be used to support other research in the future and may be shared anonymously with other researchers.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 6 - I understand that that the anonymised data collected about my child will be uploaded and shared to the UK data service or equivalent online repository.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Statement 7 - I agree that my child can take part in the above study.

○ Agree (1)

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Parent/Guardian Full Name

____

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Date

____

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent Parent/Guardian Signature

Display this question:

If Consent = Child is under 18 and I will complete this on their behalf

Parental Consent An assent form will be provided for your child to complete on the day of data collection, and if your child does not want to participate then they do not have to give assent and only if they wish to they can assent.

End of Block: Parental Consent Form

Start of Block: Physical Activity Readiness Questionnaire

PAR-Q Please answer the following questions in the perspective of whoever is partaking in the study. If you have consented on behalf of your child, please answer the following questions on behalf of them. If you have consented on behalf of yourself, please answer the following questions about yourself. If you have any doubts or difficulty with the questions, please ask Bethany Thompson for guidance. These questions are to determine whether the proposed exercise is appropriate for the participant. These answers will be kept strictly confidential. There are 28 questions to answer in this section.

PAR-Q Q1 - Have you been diagnosed with a cardiovascular disease?

- Yes (1)
- No (2)

PAR-Q Q2 - Have you ever had a cardiac event? (e.g. stroke, heart attack/myocardial infarction)

- Yes (1)
- No (2)

PAR-Q Q3 - Have you been diagnosed with a pulmonary disease, excluding asthma? (e.g. COPD)

- Yes (1)
- No (2)

PAR-Q Q4 - Have you been diagnosed with asthma?

- Yes (1)
- No (2)

PAR-Q Q5 - Have you been diagnosed with diabetes?

- Yes (1)
- No (2)

PAR-Q Q6 - Have you been diagnosed with kidney (renal) disease?

○ Yes (1)

○ No (2)

PAR-Q Q7 - Are you taking any medication for a known disease?

○ Yes (1)

○ No (2)

Page Break

PAR-Q Q8 - Do you feel pain in your chest when you undertake physical activity?

- Yes (1)
- No (2)

PAR-Q Q9 - In the last month, have you had pains in your chest when not doing physical activity?

- Yes (1)
- No (2)

PAR-Q Q10 - Do you ever lose balance because of dizziness, or do you ever lose consciousness?

- Yes (1)
- No (2)

PAR-Q Q11 - Do you ever experience unusual shortness of breath? (e.g. at rest)

- Yes (1)
- No (2)

PAR-Q Q12 - Has your doctor every advised you not to take part in vigorous exercise?

- Yes (1)
- No (2)

Page Break

*

PAR-Q Q13 - What is your date of birth (DD/MM/YYYY)?

____

PAR-Q Q14 - Is there a history of heart disease or cardiac events in your immediate family?

◯ Yes (1)

◯ No (2)

PAR-Q Q15 - Has a medical practitioner ever said you have high blood pressure?

◯ Yes (1)

◯ No (2)

PAR-Q Q16 - Have you ever taken medication for blood pressure?

◯ Yes (1)

◯ No (2)

PAR-Q Q17 - Has a medical practitioner ever said you have raised blood cholesterol?

◯ Yes (1)

◯ No (2)

PAR-Q Q18 - Have you ever taken medication to lower your cholesterol?

- Yes (1)
- No (2)

PAR-Q Q19 - Have you smoked in the last 6 months?

- Yes (1)
- No (2)

PAR-Q Q20 - Do you participate in regular physical activity?

- Yes (1)
- No (2)

PAR-Q Q21 - Are you accustomed to vigorous or high intensity exercise of approx. 1 hour per week?

- Yes (1)
- No (2)

Page Break

PAR-Q Q22 - Are you currently taking any additional medication not disclosed?

- Yes (1)
- No (2)

PAR-Q Q23 - If yes, please provide information regarding your medication

____

PAR-Q Q24 - Have you had a cold or feverish illness in the last month?

- Yes (1)
- No (2)

PAR-Q Q25 - Do you suffer from back pain that is made worse by exercise?

- Yes (1)
- No (2)

PAR-Q Q26 - Do you have any joint or bone problems which may be made worse with exercise?

- Yes (1)
- No (2)

PAR-Q Q27 - Have you ever had viral hepatitis?

- Yes (1)
- No (2)

PAR-Q Q28 - If you are female, to your knowledge, are you pregnant?

- Yes (1)
- No (2)

Page Break

PAR-Q I have completed the physical activity readiness questionnaire to the best of my knowledge and any questions I had have been answered to my full satisfaction.

PAR-Q Have you answered these questions on behalf of yourself or your child?

- ◯ Myself (1)
- ◯ My child (2)

Display this question:

If PAR-Q = Myself

PAR-Q Full Name, as registered with your school

____

Display this question:

If PAR-Q = My child

PAR-Q Parent/Guardian Full Name

____

PAR-Q Date

____

PAR-Q Signature

End of Block: Physical Activity Readiness Questionnaire

Start of Block: Physical Activity Readiness Questionnaire

Display this question:

If PAR-Q = No

And PAR-Q = No

And PAR-Q = No

And PAR-Q = No

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And PAR-Q = No

PAR-Q PAR-Q Outcome Based on your answers about the participant, they are allowed to partake in this study.

Display this question:

If PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

Or PAR-Q = Yes

PAR-Q PAR-Q Outcome Based on your answers about the participant, it is uncertain that they are allowed to partake in this study. If the participant wants to take part, please provide more information so the research team can decide if it is safe for them to do so.

____

End of Block: Physical Activity Readiness Questionnaire

Appendix 3 – Parental Consent Form (Paper Version)

University of Essex – Parental Consent Form

Project Title:

Relationships Between Video Gaming and Fitness Components in Adolescents

Research Team:

Bethany Thompson, Dr Henry Chung, Dr Mike Rogerson

Department:

School of Sport, Rehabilitation and Exercise Science (SRES)

Please initial boxes below

1. I confirm that I have read and understood the Participant Information Sheet Dated 06/11/2024 for the above study. I have had an opportunity to consider the information, ask questions and have has these questions answered satisfactorily.	
2. I understand that my child's participation is voluntary and that they are free to withdraw from the project at any time without giving any reason and without penalty. I understand that any data collected up to the point of anonymisation will be destroyed if they withdraw. If they withdraw after data have been anonymised, researchers will be unable to identify and remove my data.	
3. I understand that the interventions used in this study might require some physical movement or activity and may not be suitable for participants with health or medical conditions. I confirm that my child is uninjured and has no health or medical conditions that would prevent them from participating in this study.	
4. I understand that the identifiable data provided will be securely stored and accessible only to members of the research team directly involved in the project, and that confidentiality will be maintained.	
5. I understand that the data collected about my child will be used to support other research in the future and may be shared anonymously with other researchers.	
6. I understand that that the anonymised data collected about my child will be uploaded and shared to the UK data service or equivalent online repository.	
7. I agree that my child can take part in the above study.	

Child Name ____________________________________

Parental Name Date Parental Signature

_______________________________ _________________ ________________________

Researcher Name Date Researcher Signature

_______________________________ _________________ ________________________

Appendix 4 – Participant Assent and Physical Activity Readiness Questionnaire Form

MSD Assent and Lifestyle Questionnaire

Start of Block: Assent

Assent Have you or your parent/guardian given consent on behalf of you for this study?

○ Myself (4)

○ My parent/guardian (5)

End of Block: Assent

Start of Block: Assent Form

Display this question:

If Assent = My parent/guardian

Assent Form Participant Assent Form Research Team: Bethany Thompson, Dr Henry Chung, Dr Mike Rogerson Assent Form v1: 06/11/2024 ERAMS reference: ETHH2425-0392

Display this question:

If Assent = My parent/guardian

Assent Form Statement 1 - I confirm that I have read and understood the Participant Information Sheet dated 06/11/2024 for the above study. I have had an opportunity to consider the information, ask questions and have has these questions answered.

○ Agree (1)

Display this question:

If Assent = My parent/guardian

Assent Form Statement 2 - I understand that my participation is voluntary and that I am free to withdraw from the project at any time without giving any reason and without penalty.

○ Agree (1)

Display this question:

If Assent = My parent/guardian

Assent Form Statement 3 - I agree to take part in the above study.

○ Agree (1)

Display this question:

If Assent = My parent/guardian

Assent Form Your Full Name, as registered with your school

____

Display this question:

If Assent = My parent/guardian

Assent Form Date

____

End of Block: Assent Form

Start of Block: Participant Information

Participant Info What is your age?

____

Participant Info What is your biological sex (as assigned at birth)?

- Female (1)
- Male (2)
- Prefer not to say (3)

End of Block: Participant Information

Start of Block: Physical Activity Readiness Questionnaire

If you have any doubts or difficulty with the questions, please ask Bethany Thompson for guidance. These questions are to determine whether the proposed exercise is appropriate for the participant. These answers will be kept strictly confidential. There are 28 questions to answer in this section.

Q1 - Have you been diagnosed with a cardiovascular disease?

- Yes (1)
- No (2)

Q2 - Have you ever had a cardiac event? (e.g. stroke, heart attack/myocardial infarction)

- Yes (1)
- No (2)

Q3 - Have you been diagnosed with a pulmonary disease, excluding asthma? (e.g. COPD)

- Yes (1)
- No (2)

Q4 - Have you been diagnosed with asthma?

- ◯ Yes (1)
- ◯ No (2)

Q5 - Have you been diagnosed with diabetes?

- ◯ Yes (1)
- ◯ No (2)

Q6 - Have you been diagnosed with kidney (renal) disease?

- ◯ Yes (1)
- ◯ No (2)

Q7 - Are you taking any medication for a known disease?

- ◯ Yes (1)
- ◯ No (2)

Page Break

Q8 - Do you feel pain in your chest when you undertake physical activity?

- Yes (1)
- No (2)

Q9 - In the last month, have you had pains in your chest when not doing physical activity?

- Yes (1)
- No (2)

Q10 - Do you ever lose balance because of dizziness, or do you ever lose consciousness?

- Yes (1)
- No (2)

Q11 - Do you ever experience unusual shortness of breath? (e.g. at rest)

- Yes (1)
- No (2)

Q12 - Has your doctor every advised you not to take part in vigorous exercise?

- Yes (1)
- No (2)

Page Break

*

Q13 - What is your date of birth (DD/MM/YYYY)?

____

Q14 - Is there a history of heart disease or cardiac events in your immediate family?

○ Yes (1)

○ No (2)

Q15 - Has a medical practitioner ever said you have high blood pressure?

○ Yes (1)

○ No (2)

Q16 - Have you ever taken medication for blood pressure?

○ Yes (1)

○ No (2)

Q17 - Has a medical practitioner ever said you have raised blood cholesterol?

○ Yes (1)

○ No (2)

Q18 - Have you ever taken medication to lower your cholesterol?

- Yes (1)
- No (2)

Q19 - Have you smoked in the last 6 months?

- Yes (1)
- No (2)

Q20 - Do you participate in regular physical activity?

- Yes (1)
- No (2)

Q21 - Are you accustomed to vigorous or high intensity exercise of approx. 1 hour per week?

- Yes (1)
- No (2)

Page Break

Q22 - Are you currently taking any additional medication not disclosed?

- Yes (1)
- No (2)

Q23 - If yes, please provide information regarding your medication

____

Q24 - Have you had a cold or feverish illness in the last month?

- Yes (1)
- No (2)

Q25 - Do you suffer from back pain that is made worse by exercise?

- Yes (1)
- No (2)

Q26 - Do you have any joint or bone problems which may be made worse with exercise?

- Yes (1)
- No (2)

Q27 - Have you ever had viral hepatitis?

○ Yes (1)

○ No (2)

Q28 - If you are female, to your knowledge, are you pregnant?

○ Yes (1)

○ No (2)

Page Break

I have completed the physical activity readiness questionnaire to the best of my knowledge and any questions I had have been answered to my full satisfaction.

Full Name, as registered with your school

____

Date

____

Signature

End of Block: Physical Activity Readiness Questionnaire

Start of Block: Physical Activity Readiness Questionnaire

Display this question:

If = No

Or = No

Or = No

Or = No

Or = No

Or = No

Or = No

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Q1 PAR-Q Outcome Based on your answers, you are allowed to partake in this study.

Display this question:

If = Yes

Or = Yes

Or = Yes

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Or = Yes

Q2 PAR-Q Outcome Based on your answers, it is uncertain that you are allowed to partake in this study. Please provide more information so the research team can decide if it is safe for you to partake in this study.

____

End of Block: Physical Activity Readiness Questionnaire

Start of Block: Questions about your Video Gaming Habits

Video Gaming Habits Do you play/engage in video games on console, PC or VR?

- Yes (1)
- No (2)

Skip To: End of Block If Video Gaming Habits = No

Page Break

Video Gaming Habits Q1 - Which console/PC do you use for video gaming?

- ☐ Xbox (1)
- ☐ Playstation (2)
- ☐ PC (3)
- ☐ Handhelds e.g. switch (8)
- ☐ VR (9)
- ☐ Wii (10)
- ☐ Other (11) ____

Page Break

Display this question:

If Video Gaming Habits = Xbox

Video Gaming Habits Q2 - How many hours per week do you spend on Xbox?

____

Display this question:

If Video Gaming Habits = Playstation

Video Gaming Habits Q2 - How many hours per week do you spend on PlayStation?

____

Display this question:

If Video Gaming Habits = PC

Video Gaming Habits Q2 - How many hours per week do you spend on PC?

____

Display this question:

If Video Gaming Habits = Handhelds e.g. switch

Video Gaming Habits Q2 - How many hours per week do you spend on handheld devices?

____

Display this question:

If Video Gaming Habits = VR

Video Gaming Habits Q2 - How many hours per week do you spend on VR?

____

Display this question:

If Video Gaming Habits = Wii

Video Gaming Habits Q2 - How many hours per week do you spend on Wii?

____

Display this question:

If Video Gaming Habits = VR

Video Gaming Habits Q2 - How many hours per week do you spend on other video gaming consoles?

____

Page Break

Video Gaming Habits Q3 - What type of video games do you play?

- ☐ Action/Adventure (1)
- ☐ Sports (2)
- ☐ Shooter (3)
- ☐ Survival (4)
- ☐ Role Playing (RPG) (5)
- ☐ Multiplayer Online Battle Arena (6)
- ☐ Plaformer (7)
- ☐ Fighting (9)
- ☐ Racing (10)
- ☐ Other (11) ____

Video Gaming Habits Q4 - Which games do you play most often? E.g. Call of Duty

____

Video Gaming Habits Q5 - What level do you play at?

- ○ Beginner (1)
- ○ Intermediate (2)
- ○ Expert (3)
- ○ Other (4) ____

Video Gaming Habits Q6 - Do you play at a competitive level, e.g., esports?

- ○ Yes (1)
- ○ No (2)

End of Block: Questions about your Video Gaming Habits

Start of Block: Questions about your Physical Activity Habits

PA Habits Q1 - In the past week, on how many days have you done a total of 30 minutes or more of physical activity, which was enough to raise your breathing rate? This may include sport, traditional games, exercise and brisk walking or cycling for recreation or to get to and from places.

◯ 0 (1)

◯ 1 (3)

◯ 2 (4)

◯ 3 (5)

◯ 4 (6)

◯ 5 (7)

◯ 6 (8)

◯ 7 (9)

PA Habits Q2 - In the past week, how many hours in total did you spend doing physical activity which was enough to raise your breathing rate?

◯ 0-1 (1)

◯ 1-3 (2)

◯ 3-5 (3)

◯ 5-7 (4)

◯ 7+ (5)

PA Habits Q3 - Please select from the list below to indicate which types of physical activity you often do (at least once per month), NOT including PE lessons at school/college:

- ▢ Resistance exercise (1)
- ▢ Endurance exercise (2)
- ▢ Aerobic classes (3)
- ▢ Competitive sport (4)
- ▢ Non-competitive sport (6)
- ▢ Swimming (7)
- ▢ Running (8)
- ▢ Cycling (9)
- ▢ Walking (10)
- ▢ Other (11) ____

End of Block: Questions about your Physical Activity Habits

Appendix 5 – Generalised Additive Modelling R Script

Generalised Additive Modelling

1) fit the GAM model

the default k = 10 for the basis dimension was too large of a starting point since there are less than 10 different data points within physical_activity and age

lowest possible k was 3 for all three smoothing terms, highest possible k was 20 for video_gaming, 7 for physical_activity, and 8 for age

start them all off with k = 3, as this is the lowest k dimension possible without getting warning messages about the k basis dimension being too low

will increase k basis dimension number if gam.check() shows that the model needs k increased

```
gam_model_flex1_s <- gam(flexibility_avg ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

gam_model_bal1_s <- gam(balance_avg ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

gam_model_srt1_s <- gam(srt ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())
```

```
gam_model_hgs1_s <- gam(handgrip_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family =
gaussian())

gam_model_cmj1_s <- gam(cmj_cm ~ s(video_gaming, k = 3) + s(physical_activity,
k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

gam_model_coor1_s <- gam(coordination_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family =
gaussian())


## 2) check GAM for each CoF to see if fits well or not

# only need to raise k if k-index < 0.9 and/or p-value < 0.05


gam.check(gam_model_flex1_s)

# k-index: VG - 1.03, PA - 1.11, age - 0.95. p-value: VG - 0.64, PA - 0.94, age - 0.24.

# no indication to raise k


gam.check(gam_model_bal1_s)

# k-index: VG - 1.00, PA - 0.94, age - 0.95. p-value: VG - 0.42, PA - 0.17, age - 0.21.

# no indication to raise k


gam.check(gam_model_srt1_s)
```

k-index: VG - 1.09, PA - 1.09, age - 0.94. p-value: VG - 0.88, PA - 0.86, age - 0.12.

no indication to raise k

gam.check(gam_model_hgs1_s)

k-index: VG - 1.03, PA - 0.94, age - 0.83. p-value: VG - 0.64, PA - 0.21, age - 0.005.

indication of k-index 0.83 and p-value 0.005 for age to increase k basis dimension number

gam.check(gam_model_cmj1_s)

k-index: VG - 0.98, PA - 1.10, age - 1.06. p-value: VG - 0.38, PA - 0.89, age - 0.72.

no indication to raise k

gam.check(gam_model_coor1_s)

k-index: VG - 0.99, PA - 0.99, age - 0.87. p-value: VG - 0.44, PA - 0.37, age - 0.035.

indication of k-index 0.87 and p-value 0.035 for age to increase k basis dimension number

3) since handgrip strength and coordination didn't have high enough k = x for age, go up to 4, 5, 6, 7, and 8 and check each time!!

```
# Handgrip Strength

gam_model_hgs4_s <- gam(handgrip_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 4), data = MSD_Test, family = gaussian())

gam.check(gam_model_hgs4_s)

# p-value: age < 0.001, therefore need to increase k for age again


gam_model_hgs5_s <- gam(handgrip_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 5), data = MSD_Test, family = gaussian())

gam.check(gam_model_hgs5_s)

# p-value: age - 0.02, therefore need to increase k for age again


gam_model_hgs6_s <- gam(handgrip_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 6), data = MSD_Test, family = gaussian())

gam.check(gam_model_hgs6_s)

# p-value: age - 0.025, therefore need to increase k for age again


gam_model_hgs7_s <- gam(handgrip_h ~ s(video_gaming, k = 3) +
s(physical_activity, k = 3) + s(age, k = 7), data = MSD_Test, family = gaussian())

gam.check(gam_model_hgs7_s)

# p-value: age - 0.015, therefore need to increase k for age again
```

gam_model_hgs8_s <- gam(handgrip_h ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 8), data = MSD_Test, family = gaussian())

gam.check(gam_model_hgs8_s)

k = 8 is the maximum the basis dimension can be as there are only 8 different data points, ages 11-18

Coordination

gam_model_coor4_s <- gam(coordination_h ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 4), data = MSD_Test, family = gaussian())

gam.check(gam_model_coor4_s)

p-value: age - 0.055, therefore no indication to raise k again

4) Final GAM choices

Flexibility

gam_model_flex_s <- gam(flexibility_avg ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

Balance

gam_model_bal_s <- gam(balance_avg ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

Reaction time

gam_model_srt_s <- gam(srt ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

Handgrip strength

gam_model_hgs_s <- gam(handgrip_h ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 8) + sex, data = MSD_Test, family = gaussian())

Jump height

gam_model_cmj_s <- gam(cmj_cm ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 3) + sex, data = MSD_Test, family = gaussian())

Coordination

gam_model_coor_s <- gam(coordination_h ~ s(video_gaming, k = 3) + s(physical_activity, k = 3) + s(age, k = 4) + sex, data = MSD_Test, family = gaussian())

```
## 5) Output from each model

summary(gam_model_flex_s)
summary(gam_model_bal_s)
summary(gam_model_srt_s)
summary(gam_model_hgs_s)
summary(gam_model_cmj_s)
summary(gam_model_coor_s)

## 6) after identifying which smooth term in each GAM significantly contribute to the model, we need to see in what way (increase/decrease)?
# 6.1) Flexibility

plot(gam_model_flex_s, select = 1) # s(video gaming) decreases flexibility
plot(gam_model_flex_s, select = 2) # s(phsyical_activity) increases flexibility
plot(gam_model_flex_s, select = 3) # s(age) increases flexibility

# 6.2) Balance
```

```
plot(gam_model_bal_s, select = 2) # s(physical_activity) increases balance

plot(gam_model_bal_s, select = 3) # s(age) increases balance


# 6.3) Reaction Time


plot(gam_model_srt_s, select = 2) # s(physical_activity) decreases reaction time

plot(gam_model_srt_s, select = 3) # s(age) decreases reaction time


# 6.4) Handgrip Strength


plot(gam_model_hgs_s, select = 3) # s(age) increases handgrip strength


# 6.5) Countermovement Jump


plot(gam_model_cmj_s, select = 3) # s(age) increases jump height


# 6.6) Coordination


plot(gam_model_coor_s, select = 2) # s(physical_activity) increases coordination

plot(gam_model_coor_s, select = 3) # s(age) increases coordination
```