Aus dem Institut für Bewegungstherapie
und bewegungsorientierte Prävention und Rehabilitation
der Deutschen Sporthochschule Köln

Muskuloskelettale Belastung und Beanspruchung im E-Sport: Von der explorativen Analyse zur Modellentwicklung

Von der Deutschen Sporthochschule Köln

zur Erlangung des akademischen Grades

Doktor der Sportwissenschaft

angenommene Dissertation

vorgelegt von

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Köln 2025

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Datum der Disputation:	17.11.2025

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Die vorliegende kumulative Dissertationsschrift umfasst drei wissenschaftliche Peer-Review-Artikel, die in international anerkannten Fachjournalen publiziert wurden.

Studie I:

Tholl, C., Bickmann, P., Wechsler, K., Froböse, I. & Grieben, C. (2022). Musculoskeletal disorders in video gamers - a systematic review. *BMC musculoskeletal disorders*, *23*(1), 678. https://doi.org/10.1186/s12891-022-05614-0

Studie II:

Tholl, C., Soffner, M. & Froböse, I. (2024). How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming. *Frontiers in sports and active living*, *6*, 1370485. https://doi.org/10.3389/fspor.2024.1370485

Studie III:

Tholl, C., Hansen, L., & Froböse, I. (2025). Wrist extensor fatigue and game-genre-specific kinematic changes in esports athletes: a quasi-experimental study. BMC sports science, medicine & rehabilitation, 17(1), 261. https://doi.org/10.1186/s13102-025-01305-0

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Diese Dissertationsschrift wurde mit Unterstützung generativer KI angepasst und optimiert. Die verwendeten KI-Anwendungen kamen ausschließlich zur Strukturierung der Arbeit, zur Bildgenerierung sowie zur sprachlichen Überarbeitung zum Einsatz.

Danksagung

Mein besonderer Dank gilt meinem Betreuer und Doktorvater Univ.-Prof. Dr. Ingo Froböse, der mit seiner Offenheit und seinem visionären Blick die Promotion in einem so ungewöhnlichen Themengebiet erst möglich gemacht hat. Er hat mich immer ermutigt, meine eigene wissenschaftliche Arbeit kritisch zu hinterfragen und den Bezug zur Praxis nie aus den Augen zu verlieren. Danke für die vielen Jahre respektvoller Zusammenarbeit, die wertvolle Unterstützung meiner wissenschaftlichen Laufbahn und deine stets empathische Art.

Mein Dank gilt auch allen Kolleg*innen des Instituts für Bewegungstherapie und bewegungsorientierte Prävention und Rehabilitation für den stetigen konstruktiven und produktiven Austausch, das gegenseitige Motivieren in schweren Phasen und für das entspannte, kollegiale Miteinander. Insbesondere danke ich Dr. Bianca Biallas und Dr. Christiane Wilke, die sich unermüdlich für meine Stelle(n) eingesetzt und damit den Weg für meine Promotion geebnet haben. Ebenso danke ich meinen (ehemaligen) Kolleg*innen aus der E-Sport-Forschungsgruppe, die mich aktiv bei meinen ersten und auch letzten Schritten der Promotion unterstützt und begleitet haben.

Danke an meine Freunde, die mich motiviert, abgelenkt oder auch auf andere Gedanken gebracht und mir immer wieder aufgezeigt haben, wie wichtig ein Leben abseits der Wissenschaft ist. Speziell möchte ich Dr. Timo Sonntag und Lasse Hansen danken für ihre vielfältige Unterstützung und für eure wundervolle Freundschaft.

Der größte Dank gilt meiner Familie und meiner Lebenspartnerin – danke, dass ihr mir diesen Weg ermöglicht und mich in jeder Lebenslage unterstützt und ermutigt habt. Ohne eure bedingungslose Liebe wäre diese Arbeit nicht möglich gewesen. Danke Angie, dass du immer an meiner Seite warst, für deine unendliche Geduld, dein entgegengebrachtes Verständnis und dafür, dass du mich immer wieder an die wichtigen Dinge im Leben erinnerst!

Vielen herzlichen Dank euch allen!

I. Inhaltsverzeichnis

II. Abkürzungsverzeichnis

Abkürzung	Deutsch	Englisch
APM	Aktionen pro Minute	actions per minute
BMI	Körpermassenindex	Body Mass Index
CR10	Kategorialskala	Category-Ratio-Scale
ebd.	ebenda	ibid
EMG	Elektromyographie	electromyography
E-Sport/esports	elektronischer Sport	electronic sports
FITZ	Frequenz, Intensität, Typ, Zeit	frequency, intensity, type, time
HRV	Herzratenvariabilität	heart rate variability
JASA	Gemeinsame Analyse von Spektrum und Amplitude	Joint Analysis of Spectrum and Amplitude
KI	Künstliche Intelligenz	artificial intelligence
MSE/MSDs	Muskel-Skelett-Erkrankungen	musculoskeletal disorders
WHO	Weltgesundheitsorganisation	World Health Organization
WKV	Skala zur wahrgenommenen körperlichen Verfassung	Perceived Physical State Scale
ZNS	Zentrales Nervensystem	central nervous system

III. Abbildungsverzeichnis

IV. Zusammenfassung der Dissertation

Videospiele haben sich in den vergangenen Dekaden als eine der beliebtesten Freizeitaktivitäten etabliert und sind inzwischen fester Bestandteil unserer Gesellschaft und Kultur. Das kompetitive Videospielen, auch bekannt als elektronischer Sport (E-Sport), ist ein wesentlicher Bestandteil des Videospielsektors und stellt sowohl die Gesellschaft als auch die Wissenschaft vor neue Herausforderungen. Die Lebensrealität von E-Sportler*innen ist gegenwärtig gekennzeichnet durch dauerhaftes Sitzverhalten, monotone Körperhaltungen und repetitive Bewegungen der oberen Extremitäten, kombiniert mit kognitiven Höchstleistungen. Diese langandauernden und sich wiederholenden körperlichen Belastungen können zu einer erhöhten Beanspruchung des Muskel-Skelett-Systems führen, was das Risiko für Muskel-Skelett-Erkrankungen (MSE) steigern kann. Derzeit mangelt es jedoch an empirisch gesicherter Evidenz zur körperlichen Belastung und Beanspruchung im E-Sport sowie zu deren gesundheitlichen Konsequenzen. Ziel dieser Arbeit ist daher zu untersuchen, inwieweit das Videospielen das muskuloskelettale System beansprucht und welche physischen Belastungsfaktoren im E-Sport vorherrschen. Die Erkenntnisse sollen genutzt werden, um ein erstes Belastungs-Beanspruchungsmodell des E-Sports zu entwickeln.

In Studie I wurde mithilfe einer systematischen Übersichtsarbeit untersucht, inwiefern Videospielen einen negativen Einfluss auf das muskuloskelettale System haben kann. Die Analyse ergab, dass die Mehrheit der 16 inkludierten Studien einen signifikant negativen Effekt der Videospielzeit auf das Muskel-Skelett-System aufzeigte. Insbesondere exzessive Videospielzeiten (>3 Stunden/Tag) erhöhten die Wahrscheinlichkeit für das Auftreten von MSE. Die am häufigsten betroffenen Regionen waren der Nacken, die Schultern und der Rücken. Die Qualität der Studien war überwiegend hoch, mit einem geringen-moderaten Risiko für Verzerrungen. Die Ergebnisse deuten darauf hin, dass bereits bei jungen Menschen, die häufig Videospiele spielen, die Wahrscheinlichkeit für das Auftreten von MSE steigt. Die systematische Übersichtsarbeit zeigte jedoch auch, dass der aktuelle Forschungsstand im Wesentlichen auf Querschnittsanalysen basiert. Ob protektiven Verhaltensweisen wie körperliche Aktivität oder regelmäßiger Sport das Risiko für MSE reduzieren können, gilt es somit in longitudinalen Folgestudien zu untersuchen.

Studie II & III basieren auf einer gemeinsamen quasi-experimentellen Untersuchung, in der sowohl subjektive als auch objektive Beanspruchungsparameter während einer standardisierten Videospielexposition analysiert wurden. Die Stichprobe umfasste 32 gesunde, männliche E-Sportler im Alter von 23,8 ± 3,4 Jahren. Die Teilnehmenden durchliefen zwei kompetitive Videospieleinheiten mit einer jeweiligen Dauer von 90 bis 120 Minuten, die durch eine zehnminütige passive Sitzpause unterbrochen wurde. Studie II untersuchte die subjektive körperliche Anstrengung (Borg-Skala) sowie die wahrgenommene körperliche Verfassung (WKV), welche jeweils vor und nach den Videospieleinheiten erhoben wurden. Mit zunehmender Spieldauer zeigte sich eine signifikante Abnahme der WKV sowie eine Zunahme der Borg-Skala. Die zehnminütige Pause führte zu einer signifikanten temporären Reduktion der subjektiven Beanspruchungsparameter, mit Ausnahme der WKV-Dimension „Gesundheit". Studie III befasste sich mit der muskulären Ermüdung des Musculus trapezius pars descendens (*Trapezius*) und des Musculus extensor digitorum (*Handgelenksextensoren*) sowie mit kinematischen Parametern der Maushand. Die Ergebnisse zeigten, dass lediglich bei den Handgelenksextensoren ein signifikanter Anstieg der muskulären Ermüdung nach beiden kompetitiven Videospieleinheiten festgestellt wurde, während die kinematischen Daten über die Spieldauer hinweg konstant blieben. Die passive Pause hatte keinen messbaren Einfluss auf die objektiv erfassten Beanspruchungsparameter. Diese Befunde legen nahe, dass sich die subjektiven und objektiven Beanspruchungsparameter zwar zeitlich vergleichbar entwickeln, jedoch unterschiedlich auf Erholungsphasen reagieren. Während sich die subjektive Beanspruchung in der Erholungsphase signifikant reduzierte, blieben objektive Beanspruchungsparameter unverändert, was auf eine mögliche Diskrepanz zwischen wahrgenommener und tatsächlicher Beanspruchung hinweist. Das verwendete quasi-experimentelle Studiendesign erlaubt jedoch lediglich die Ableitung erster Indizien und keine abschließenden kausalen Aussagen.

Die in dieser Arbeit präsentierten Studien stützen die Annahme, dass ein erhöhter Videospielkonsum mit einer gesteigerten Prävalenz für MSE assoziiert ist. Darüber hinaus konnten erstmals unter realitätsnahen Bedingungen die körperlichen Belastungen und die daraus resultierenden Beanspruchungen im E-Sport aufgezeigt werden. Hervorzuheben ist die konsistente Verschlechterung sowohl subjektiver als auch objektiver Beanspruchungsparameter bei längerer Spieldauer. Auf Basis dieser empirischen Befunde und theoretischen Vorüberlegungen wurde ein adaptives

Belastungs-Beanspruchungsmodell für den E-Sport entwickelt. Das Modell bietet forschungsleitende Impulse sowie praxisorientierte Handlungsempfehlungen zur Prävention, gezielten Trainingssteuerung und zum Gesundheitsmanagement von E-Sportler*innen.

V. Summary of the doctoral thesis

In recent decades, video games have become one of the most popular leisure activities and an integral part of our society and culture. Competitive video gaming, also known as electronic sports (esports), has emerged as a major component of this sector, posing new challenges for both society and the scientific community. Esports athletes are frequently exposed to prolonged sedentary behavior, monotonous postures, and repetitive upper-limb movements. These continuous, repetitive physical loads may place considerable strain on the musculoskeletal system and potentially increase the risk of musculoskeletal disorders (MSDs). However, there is currently a lack of robust empirical evidence regarding the physical burdens in esports and their potential health consequences. The objective of this dissertation is to investigate the extent to which competitive video gaming imposes musculoskeletal exertion and to identify specific physical load factors in esports. In addition, the findings will inform the development of a preliminary internal and external load model tailored to the context of esports.

Study I employed a systematic review to examine potential adverse effects of video gaming on the musculoskeletal system. The review of 16 studies revealed an association between video game playtime and negative musculoskeletal outcomes. In particular, excessive video game playtime (>3 hours/day) was linked to increased odds ratios for MSDs. The most frequently affected anatomical regions were the neck, shoulders, and back. The overall risk of bias in the included studies was rated as low to moderate. The evidence suggests that young individuals who regularly engage in video gaming may already be at an increased risk of developing MSDs. Protective behaviors, such as regular physical activity, may help mitigate this risk. The findings highlight that existing research is predominantly based on cross-sectional designs, limiting causal interpretations.

Studies II and III were based on a quasi-experimental design, assessing both subjective and objective parameters of physical exertion during a standardized competitive gaming session. Thirty-two healthy male esports athletes (23.8 ± 3.4 years) participated in two competitive gaming sessions of 90–120 minutes each, separated by a 10-minute passive sitting break. Study II examined the perceived exertion using the Borg scale and the perceived physical state scale. Both were assessed before and after each gaming session. Results indicated a significant increase in perceived exertion and a decrease in perceived physical state over time. A

ten-minute break led to a temporary reduction in subjective parameters, except for the "health" dimension of the perceived physical state scale. Study III focused on the muscular fatigue of the trapezius pars descendens (*trapezius*) and the extensor digitorum (*wrist extensors*) muscles, as well as kinematic data from the mouse hand during the competitive gaming sessions. The results demonstrated that only the wrist extensors exhibited a significant increase in muscular fatigue after the two video gaming sessions, while kinematic data remained constant. The passive break had no significant effect on either muscular fatigue or kinematic variables. The findings indicate that, while the subjective and objective parameters demonstrate a comparable overall temporal pattern, they respond differently to recovery phases. In particular perceived physical exertion decreased during the break, whereas objective physiological markers remained unchanged, potentially indicating a dissociation between perceived and measured exertion. Nevertheless, due to the quasi-experimental design, the findings should be interpreted as preliminary and do not allow for definitive causal inferences.

This dissertation provides initial evidence that prolonged video gaming is associated with musculoskeletal burden and may contribute to the development of MSDs. The combination of subjective and objective data under ecologically valid conditions constitutes a novel contribution to esports research. Based on these findings and theoretical considerations, an esports-specific internal and external load model was developed, offering a conceptual foundation for future studies and practical applications in health and performance management.

1. Einleitung

Seit fast 50 Jahren wächst die Popularität und das gesellschaftliche Interesse an Videospielen kontinuierlich. Heute zählen Videospiele zu den beliebtesten Freizeitbeschäftigungen weltweit (Morse et al., 2021). Schätzungsweise 3,42 Milliarden Videospielende gab es im Jahr 2024 (Newzoo, 2024b), bei einem Marktumsatz von etwa 259,08 Milliarden Euro (Statista Market Insights, 2024). In den jüngeren Generationen ist das Videospielen besonders verbreitet, rund 90 % der Generation Z und Alpha spielen regelmäßig (Newzoo, 2024a). In Deutschland spielten im selben Jahr etwa 58 % der Deutschen zumindest gelegentlich Videospiele (game, 2024). Bemerkenswert ist, dass laut dem Verband der deutschen Games-Branche über alle Altersklassen, sozialen Schichten und Geschlechter hinweg gespielt wird (ebd.). Damit wird deutlich, dass sich Videospiele zu einem kulturellen Bestandteil unserer Gesellschaft entwickelt haben.

Ein wesentlicher Teil des Videospielsektors ist der sogenannte elektronische Sport (E-Sport), auch als kompetitives Videospielen bekannt (Jenny et al., 2017). Im Gegensatz zu Videospielenden, trainieren E-Sportler*innen gezielt, um ihre Leistungsfähigkeit zu verbessern und in Wettkämpfen unter definierten Regeln gegeneinander anzutreten (Jenny et al., 2025). Die Entwicklung von einfachen Unterhaltungsspielen hin zu hochkomplexen, wettbewerbsorientierten Disziplinen hat nicht nur die Unterhaltungsindustrie verändert, sondern auch neue Herausforderungen für die Gesellschaft geschaffen. Um (spiel-)spezifische Fähigkeiten zu entwickeln, trainieren E-Sportler*innen täglich zwischen 4 und 10 Stunden, abhängig vom Videospielgenre und ihrem individuellen Leistungsniveau (DiFrancisco-Donoghue et al., 2019; Soffner et al., 2023). Dies führt häufig zu langen, ununterbrochenen Sitzzeiten (Migliore et al., 2021) mit monotonen Körperhaltungen (Franks et al., 2022) und repetitiven Bewegungen der oberen Extremitäten (Law et al., 2023). Das physische Belastungs- und Beanspruchungsprofil von E-Sportler*innen weist daher starke Ähnlichkeiten mit dem von sitzenden Berufsgruppen wie Büroarbeitenden oder Fluglots*innen auf (Franks et al., 2022; Funk et al., 2018).

Für diese sitzenden Berufsgruppen sind die beschriebenen Belastungen mit einem erhöhten Risiko für Muskel-Skelett-Erkrankungen (MSE) assoziiert (Kok et al., 2019; Waongenngarm et al., 2018). Aufgrund der Ähnlichkeiten zwischen den physischen

Belastungsprofilen, könnte exzessives Videospielen ebenfalls mit einem erhöhten Risiko für MSE verbunden sein. Eine gesamtgesellschaftliche Relevanz besteht durch die hohen Krankheitskosten, welche durch MSE verursacht werden. Im Jahr 2020 betrugen diese 41,67 Milliarden Euro in Deutschland (Statistisches Bundesamt, 2024). Zugleich muss der hohe Anteil junger Menschen berücksichtigt werden, die im E-Sport und an Videospielaktivitäten partizipieren (Newzoo, 2024a; Rudolf et al., 2020). Da gesundheitsrelevante Verhaltensmuster bereits in jungen Jahren entstehen und häufig bis ins Erwachsenenalter persistieren (Frech, 2012), kann dies langfristige gesundheitliche Konsequenzen nach sich ziehen.

Aus diesem Grund ist es das Ziel der vorliegenden Arbeit, zu untersuchen, inwieweit das Videospielen das muskuloskelettale System beansprucht und welche physischen Belastungen im E-Sport vorherrschen. Die Ergebnisse sollen genutzt werden, um ein erstes Belastungs-Beanspruchungsmodell des E-Sports zu entwickeln. Darüber hinaus können die Ergebnisse einen wesentlichen Beitrag zu einer holistischen Trainingslehre im E-Sport leisten sowie Ansätze für präventive und rehabilitative Maßnahmen aufzeigen.

2. Wissenschaftlicher Hintergrund

2.1 Definitorische Grundlagen

Als begriffliche Grundlage dieser Arbeit ist eine klare Abgrenzung zwischen allgemeinen Videospielen und E-Sport erforderlich. Zum jetzigen Zeitpunkt fehlt es an einer einheitlichen Definition des Begriffs E-Sport (Bubna et al., 2023; Jenny et al., 2025). Entsprechend existieren divergierende Kategorisierungen, ab wann eine Person als E-Sportler*in oder E-Sport-Athlet*in gilt, was die Vergleichbarkeit zwischen Studien erschwert.

In der vorliegenden Arbeit wird Videospielen als Sammelbegriff verstanden, der sich in kompetitive und nicht-kompetitive Ausprägungen unterteilen lässt (Scholz & Nothelfer, 2022). Nicht-kompetitives Videospielen umfasst dabei Freizeitaktivitäten, die vorrangig der Unterhaltung und dem Spielspaß dienen. Demgegenüber steht der E-Sport als kompetitives Videospielen mit klarem Leistungsgedanken, welcher als regelgebundener Wettkampf zwischen menschlichen Spieler*innen unter Nutzung digitaler Spiele verstanden wird (Jenny et al., 2025). Die zugrunde liegende Definition umfasst sämtliche Leistungsstufen und differenziert nicht zwischen Amateur*innen- und Profiebene. Die Art des Eingabegeräts, sei es Computer, Konsole oder Smartphone ist dabei nicht entscheidend. Spiele, die keinen menschlichen Wettkampf beinhalten, sowie körperlich aktive Videospiele (sogenannte „*Exergames*“), werden in der vorliegenden Arbeit nicht berücksichtigt. Letztere stellen aufgrund ihrer motorischen Anforderungen eine andere Beanspruchung für das muskuloskelettale System dar (Viana et al., 2021) und unterscheiden sich grundlegend von traditionellen, überwiegend sitzend ausgeübten E-Sport-Spielen (McNulty et al., 2023). Zusammenfassend sind E-Sportler*innen Personen, die Videospiele nutzen, um im Rahmen eines regelgeleiteten, kompetitiven Formats gegen andere menschliche Kontrahent*innen anzutreten, unabhängig vom verwendeten Eingabemedium oder dem individuellen Leistungsniveau (Jenny et al., 2025; Scholz & Nothelfer, 2022). Damit wird impliziert, dass sowohl der Trainingsalltag als auch die Wettkampfsituation in der vorliegenden Arbeit berücksichtigt werden. Der Fokus der vorliegenden Arbeit liegt insbesondere auf den Rahmenbedingungen des kompetitiven Videospielens.

2.2 Belastungs-Beanspruchungskonzept

Belastung und Beanspruchung sind Begriffe aus der Arbeitswissenschaft, die verschiedene Phänomene beschreiben, jedoch häufig synonym verwendet werden. Unter Belastung versteht man alle äußeren Einflüsse, die auf einen Menschen einwirken und potenziell eine Reaktion des Organismus auslösen können (Bullinger, 1994). Hierzu zählen unter anderem die Arbeitsaufgabe, Umweltfaktoren oder organisatorische und soziale Einflüsse. Im Gegensatz dazu beschreibt Beanspruchung die Veränderung des menschlichen Organismus, welche durch äußere Einflüsse (Belastung) hervorgerufen werden kann (Bullinger, 1994). Die Art der Einflüsse und Reaktionen werden dabei nicht weiter spezifiziert. Dementsprechend können die hervorgerufenen Beanspruchungen biopsychosozial und reversibel oder irreversibel sein (Schlick et al., 2018). Die hervorgerufenen Beanspruchungen können in der Regel anhand von Beanspruchungsgrößen wie der Herz- oder Atemfrequenz, dem Blutdruck, hormonellen Veränderungen oder neurophysiologischen Parametern quantifiziert werden.

Arbeitswissenschaftliche Modelle, welche Belastung und Beanspruchung thematisieren, dienen dazu, den Zusammenhang zwischen Tätigkeitsanforderungen und den resultierenden Reaktionen auf Beschäftigte systematisch abzubilden. Das „*Job-Demands-Resources*“ Modell von Demerouti et al. (2001) beschreibt dabei, wie arbeitsbezogene Anforderungen („*demands*“), etwa Zeitdruck oder Aufgabenkomplexität, in Wechselwirkung mit verfügbaren Ressourcen („*resources*“), wie sozialer Unterstützung oder Handlungsspielräumen, Beanspruchungen oder motivationale Effekte hervorrufen können. Es dient insbesondere dazu, positive wie negative Befindensindikatoren und deren Auswirkungen im Arbeitskontext festzustellen. Im Unterschied dazu fokussiert das „*Effort-Recovery*“ Modell von Meijman und Mulder (1998) besonders den zyklischen Zusammenhang von Anstrengung und Erholung. Dabei hebt es hervor, dass unzureichende Erholungsphasen nach intensiven Belastungen zu chronischen Ermüdungszuständen und gesundheitlichen Beeinträchtigungen führen können. Diese Modelle beziehen sich vorwiegend auf arbeitsorganisatorische und psychische Faktoren, was in einer ganzheitlichen Betrachtung des Arbeitssystems unabdingbar ist. Die vorliegende Arbeit verfolgt jedoch das Ziel, speziell die körperlichen Aspekte des E-Sports zu analysieren, weshalb das Belastungs-Beanspruchungskonzept von Rohmert (1984) geeigneter ist.

Das Belastungs-Beanspruchungskonzept von Rohmert (1984) stellt einen Ursache-Wirkungs-Zusammenhang zwischen Belastung und Beanspruchung dar und bildet die Basis der modernen Arbeitswissenschaft (Hartmann, 2022). Das Ursprungsmodell bietet die Möglichkeit komplexe Sachverhalte vereinfacht und klar darzustellen, weshalb es als Basis für diese Arbeit fungiert (Abb. 1). Das Konzept beschreibt den Zusammenhang zwischen den Faktoren: Belastung, Beanspruchung und Mensch (Eigenschaften) anhand eines mechanischen Modells.

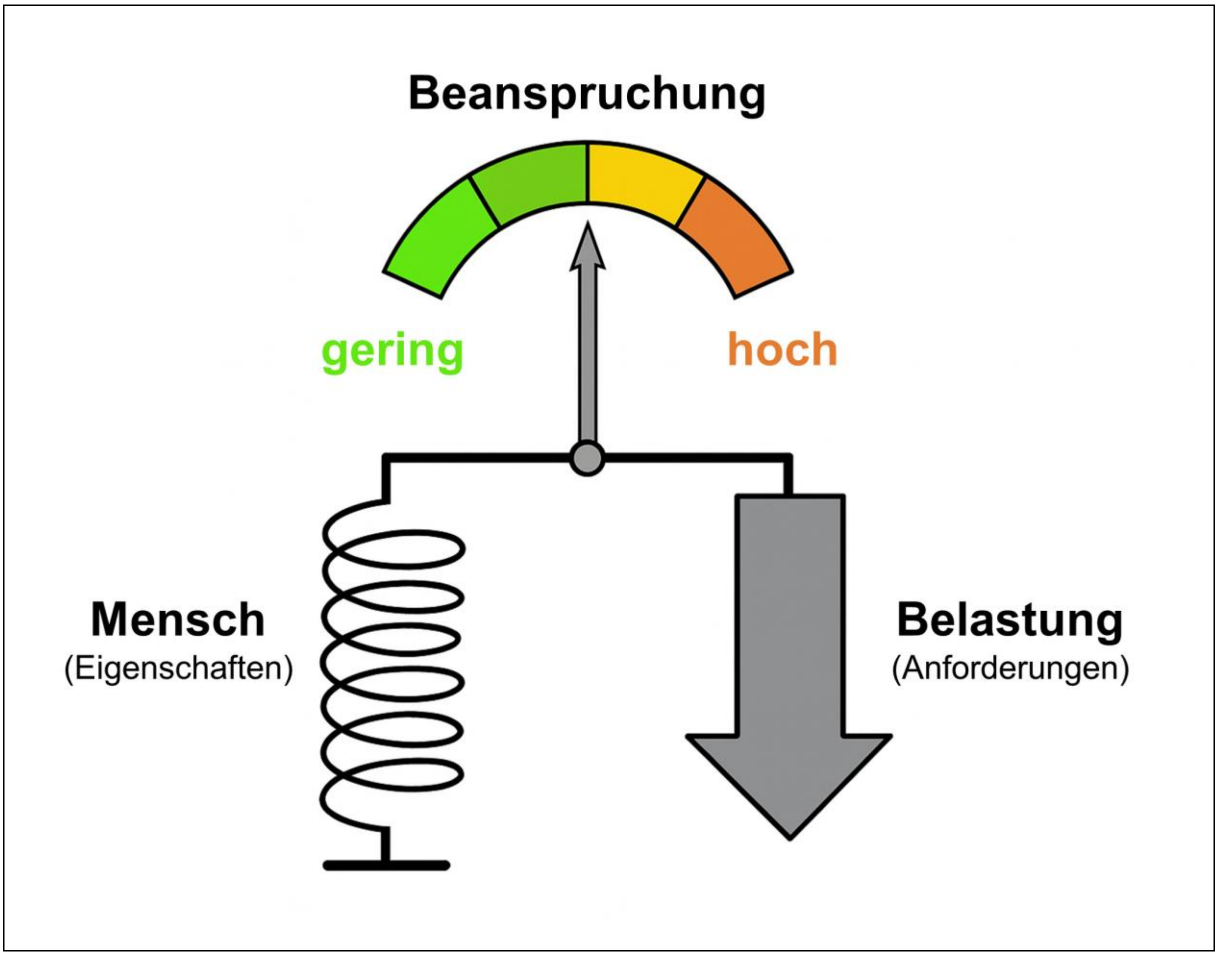

Abbildung 1: Beziehung zwischen Belastung und Beanspruchung nach Rohmert (1984) (KI-generierte Darstellung, OpenAI, 09.07.2025).

Laurig (2015) zufolge bestehen Wechselwirkungen zwischen Belastung, individuellen Eigenschaften und der daraus resultierender Beanspruchung. Demnach führt eine Veränderung der Belastung bei konstanten Eigenschaften zu einer Veränderung der Beanspruchung. Sind hingegen die Eigenschaften variabel, beeinflussen sowohl die Belastung als auch die Variation der Eigenschaften die Beanspruchung (Laurig, 2015). Dementsprechend spielen die individuellen Ressourcen (Eigenschaften) eine wesentliche Rolle, da dieselbe Belastung bei unterschiedlichen Menschen zu verschiedener Beanspruchung führen kann. Folglich beeinflussen die Ressourcen des Individuums die individuelle Beanspruchung. Anzumerken ist, dass sich Ressourcen durch (chronische) Belastung verändern können, beispielsweise durch Fatigue. In diesem Fall stellt die Fatigue eine (reversible) Abnahme von Ressourcen bei konstanter Belastung dar, die zu einer Erhöhung der Beanspruchung führt (Laurig, 2015). Reversibel ist sie dann, wenn eine Regenerationsphase den Ursprungszustand wiederherstellen kann. Damit kann die Regeneration der Ressourcen zu einer

Veränderung der Beanspruchung führen (Schlick et al., 2018). Führt dieser regenerative Prozess zu einem Ressourcenaufbau, wird es als Adaptation bezeichnet (Hartmann, 2022). Im Kontrast dazu stehen irreversible Ressourcenabnahmen (Überlastungen), welche auf Dauer zu Schädigungen des Organismus führen können (Hartmann, 2022). Auf der anderen Seite kann Unterforderung kurzfristig zu Monotonie, Ineffektivität und Unzufriedenheit führen (Schlick et al., 2018) und langfristig ebenfalls Schädigung begünstigen, im Sinne einer fehlenden Auslastung spezifischer Organsysteme (Holzgreve et al., 2023). Insbesondere das muskuloskelettale System ist auf mechanische Beanspruchung (Reize) angewiesen, da es sonst zu einem vermehrten Abbau von Gewebe kommt (Soendenbroe et al., 2022; Wisdom et al., 2015). Dementsprechend begünstigen körperlich inaktive, sedentäre Verhaltensweisen diesen Abbauprozess und damit das Risiko von muskuloskelettalen Erkrankungen.

Das Belastungs-Beanspruchungskonzept kann durch seine allgemeine Anwendbarkeit ebenfalls auf das Videospielen und den E-Sport übertragen werden. Dadurch ergibt sich die Frage, welche Belastungen und daraus resultierenden Beanspruchungen beim Videospielen und im E-Sport auftreten und ob diese gesundheitsschädlich sein könnten.

2.2.1 Analyse von Belastung und Beanspruchung

Die Analyse von Belastung und Beanspruchung ist eine wichtige präventive Maßnahme, um mögliche Folgeerkrankungen zu vermeiden. Die Methoden zur Datenerhebung solcher Analysen werden nach Winkel und Mathiassen (1994) in drei Kategorien unterteilt: Befragung, Beobachtung und Messung. Anhand von fünf weiteren Kriterien werden diese Messverfahren in Bezug auf ihre Gütekriterien beurteilt (siehe Abb. 2).

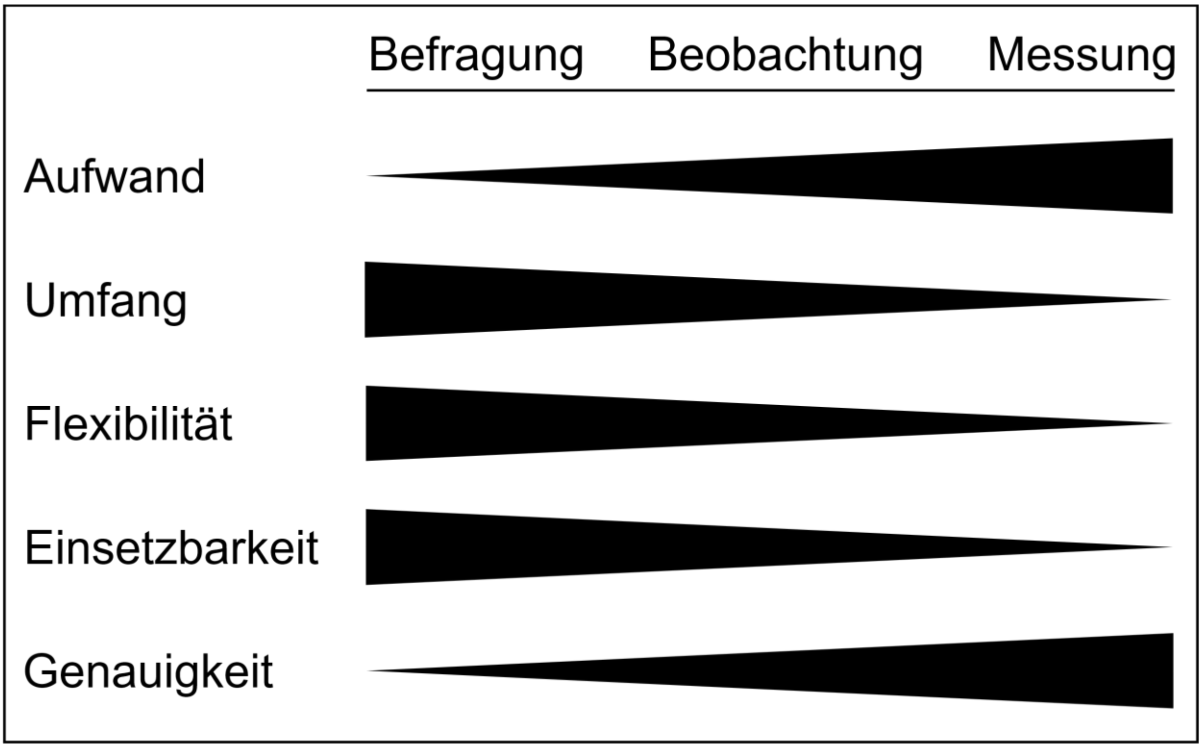

Abbildung 2: Vor- und Nachteile unterschiedlicher Verfahrensweisen der Datenerhebung (nach Winkel & Mathiassen 1994, S. 983)

Die Befragung zeichnet sich demnach durch eine hohe Flexibilität und Einsetzbarkeit, jedoch durch eine geringere Genauigkeit im Vergleich zu den anderen Verfahren aus. Zu der Befragung zählen unter anderem Interviews, Fragebögen und Bewertungsskalen, welche als subjektive Verfahren klassifiziert sind und damit eine höhere Anfälligkeit für soziale Verzerrung bieten (Döring & Bortz, 2016). Im Mittelfeld der fünf Kriterien liegen die Beobachtungen, die im Rahmen von (ergonomischen) Analysen ausschließlich zur Erfassung der Belastung geeignet sind (Hellig, 2019). Gegenstand der Beobachtung sind unter anderem die Körperhaltung, einwirkende Kräfte, Arbeitszeit und repetitive Tätigkeiten (David, 2005). Die Messung zeichnet sich durch die höchste Genauigkeit, den größten Aufwand sowie die höchste Objektivität aus. Zur Erfassung der Beanspruchung werden üblicherweise physiologische oder biochemische Messgrößen herangezogen (Rohmert, 1986). Häufig analysierte Beanspruchungsgrößen sind die Herzfrequenz, der Blutdruck, die Körperkerntemperatur oder elektromyographische Parameter. Um eine möglichst umfassende und valide Erfassung des zu untersuchenden Konstrukts zu ermöglichen, sollten im Rahmen wissenschaftlicher Untersuchungen verschiedene Erhebungsinstrumente im Sinne einer Methodentriangulation eingesetzt werden (Flick, 2011). Unter Berücksichtigung des Ziels der vorliegenden Arbeit ist es daher sinnvoll, subjektive und objektive Messverfahren zu kombinieren, um einen umfassenden Einblick in die körperliche Beanspruchung zu erhalten.

2.2.2 Herausforderungen subjektiver und objektiver Messverfahren

Aufgrund der hohen Flexibilität, unkomplizierten Nutzung, des geringen Kostenaufwands und der vergleichsweise einfachen Auswertung sind subjektive Messverfahren wie Fragebögen und Bewertungsskalen ein adäquates Mittel, insbesondere für epidemiologische Fragestellungen mit großen Stichproben (vgl. Kap. 2.2.1). Zusätzlich bieten solche Verfahren die Möglichkeit, die Beanspruchungswahrnehmung subjektiv einzuschätzen (David, 2005). Der Nachteil dieser subjektiven Verfahren liegt in der geringeren wissenschaftlichen Güte und dem hohen Risiko der Verzerrung (David, 2005; Müller et al., 2010). Speziell können weit zurückliegende Zeiträume oder ein hohes Alter zu einem Retrospektionseffekt („*recall bias*“) führen (Coughlin, 1990). Um dieser Herausforderung zu begegnen, eignen sich zur Erhebung der körperlichen Beanspruchung Fragebögen und Bewertungsskalen, die sensitiv genug sind, um Änderungen in einem kurzen Zeitraum zu erfassen. Die Borg-Skala oder „*Rate of Perceived Exertion*“ ist ein solch universelles Messverfahren, welches die wahrgenommene Anstrengung misst. Ursprünglich wurde die Skala entwickelt, um eine Belastungskontrolle während Ausdaueraktivitäten zu gewährleisten, wobei sie an die Herzfrequenz angelehnt ist (Borg, 1982). Heute gibt es vielzählige Modifikationen von dieser Skala, welche beispielsweise pneumologische Beanspruchungen oder Schmerzen erfassen (Borg, 1998). Die „*Category-Ratio-Scale*“ (CR10) begrenzt die ursprüngliche Borg-Skala auf eine 11-Punkte Skala (0-10) mit leicht exponentiellem Anstieg und findet ebenfalls in der Arbeitswissenschaft Anwendung zur Erfassung wahrgenommener (körperlicher) Beanspruchung (Takala et al., 2010). Diese Modifikation zeigt ebenfalls in sportwissenschaftlichen Untersuchungen eine gute Reliabilität und Validität (Shariat et al., 2018). Daneben ist die Skala zur wahrgenommen körperlichen Verfassung (WKV) eines der wenigen evaluierten Instrumente im deutschsprachigen Raum, das explizit die selbstberichtete, akute körperliche Beanspruchung misst und sensitiv gegenüber kurzfristigen Veränderungen ist (Kleinert, 2006).

Im Gegensatz zu subjektiven Verfahren, zeichnen sich objektive Messverfahren in der Regel durch ein hohes Maß an wissenschaftlicher Güte aus (vgl. Kap. 2.2.1). Jedoch sind diese Instrumente meist kostenintensiver und zeitaufwendiger, was den Stichprobenumfang häufig einschränkt (David, 2005). Eine dieser objektiven Messmethoden ist die Elektromyographie (EMG), welche ein breites Analysespektrum der muskulären Beanspruchung bietet. Insbesondere ist die Erfassung der muskuläre Ermüdung hervorzuheben, da diese einen Einfluss auf die Leistung und Gesundheit eines Menschen haben kann (Forman et al., 2022; Huysmans et al., 2008). Unter muskulärer Ermüdung ist eine Verringerung der maximalen Kraft- oder Leistungsproduktion als Reaktion auf kontraktile Aktivität definiert und kann in zentrale und periphere Komponenten unterteilt werden (Boyas & Guével, 2011). Die zentrale Ermüdung beeinflusst die willentliche Aktivierung der Muskeln vom zentralen Nervensystem (ZNS), wohingegen die periphere Ermüdung mit der neuromuskulären Verbindung assoziiert ist und die kontraktile Funktion der Muskeln beeinträchtigt (Forman et al., 2022). Demnach misst die EMG die muskuläre Ermüdung nur indirekt, da sie die Kraftentwicklung nicht direkt erfassen kann. Dennoch kann eine Analyse des Frequenzspektrums als indirekter Marker für muskuläre Ermüdung dienen, da eine Reduktion der Medianfrequenz im Zeitverlauf mit Ermüdung assoziiert ist (De Luca, 1984). Zusätzlich kann das Verhältnis zwischen Frequenzspektrum und EMG-Amplitude eine validere Aussage geben: Ein Anstieg der Amplitude bei simultaner Abnahme des Frequenzspektrums wird als Zeichen muskulärer Ermüdung gedeutet (Dufaug et al., 2020; Luttmann et al., 2000). In der Konsequenz hat sich die EMG als valide Methode zur Erfassung der neuromuskulären Ermüdung etabliert, wenngleich es keine direkte Quantifizierung der Kraft erlaubt.

2.3 Muskuloskelettale Anpassungen

Im Sinne des vorgestellten Belastungs-Beanspruchungskonzepts (vgl. 2.2) können sich Reize unterschiedlich auf das muskuloskelettale System auswirken. Vereinfacht dargestellt führen zeitlich limitierte, progressive und überschwellige Reize bei ausreichender Regenerationszeit und Nährstoffversorgung in der Regel zu Adaptationsprozessen im menschlichen Körper (DeWeese et al., 2015). Demnach führt ein geplantes und konsistent durchgeführtes körperliches Training zu

Anpassungsreaktionen im Körper, wodurch die muskuloskelettale Gesundheit und Leistungsfähigkeit erhalten oder gesteigert werden können. Sind im Gegensatz dazu Reize persistierend, überfordernd und durch eine unzureichende Regenerationszeit gekennzeichnet, führt dies häufig zu Überlastungen und langfristig zu Schädigungen (Hartmann, 2022). Bezogen auf den E-Sport und das Videospielen, gibt es zum jetzigen Zeitpunkt keine Hinweise in der wissenschaftlichen Literatur, die eine positive Wirkung von klassischen Videospielen auf die muskuloskelettale Gesundheit aufzeigen. Der gegenteilige Effekt wird in der Studienlage beschrieben, demnach wird vermehrter Videospielkonsum mit höheren Prävalenzen für MSE assoziiert (Lindberg et al., 2020; Torsheim et al., 2010).

Zu den MSE zählen verschiedene Erkrankungen, Schädigungen und Beschwerden, welche die Knochen, Gelenke, Muskeln oder das Bindegewebe betreffen (National Academies Press, 2020). Etwa 19,5 % der krankheitsbedingten Fehlzeiten in Deutschland gingen 2023 auf muskuloskelettale Erkrankungen zurück, Tendenz steigend (Badura et al., 2024). Die Pathogenese kann je nach Erkrankung sehr unterschiedlich sein, jedoch lassen sich übergeordnete Risikofaktoren feststellen, welche einzeln oder in der Kombination die MSE-Prävalenz erhöhen. Hierzu zählen biomechanische, psychosoziale, sozioökonomische sowie organisatorische und umweltbedingte Risikofaktoren (Kok et al., 2019). Insbesondere die physischen Ursachen werden durch Lebensstilfaktoren, wie körperliche (In-)Aktivität und ergonomische Defizite geprägt (Kok et al., 2019; Schmidt et al., 2021). Im Sinne des Belastungs-Beanspruchungskonzepts können Über- und Unterforderungen des Muskel-Skelett-Systems die Inzidenz muskuloskelettaler Erkrankungen begünstigen. Insbesondere sitzende Tätigkeiten sind häufig durch körperliche Unterforderung geprägt (Soendenbroe et al., 2022), was das Risiko von Folgeschäden erhöhen kann. Dementsprechend weisen vor allem Personen- und Berufsgruppen mit sedentärem Lebensstil ein erhöhtes Risiko für MSE auf (Baradaran Mahdavi et al., 2021; Mazaheri-Tehrani et al., 2023).

Neben dem sedentären Verhalten, zählen vor allem anhaltende repetitive Bewegungen und monotone Körperhaltungen zu physischen Risikofaktoren für MSE (Kok et al., 2019). Diese Faktoren finden sich in sitzenden Berufsgruppen wie zum Beispiel Büroarbeitenden, Fluglotsenden und Pianist*innen wieder sowie bei E-Sportler*innen (Law et al., 2023; Migliore et al., 2021). In den genannten

Berufsgruppen konnte bereits ein erhöhtes Risiko für MSE nachgewiesen werden (Arvidsson et al., 2008; Turner et al., 2023; Waongenngarm et al., 2018), wohingegen für den E-Sport eine übergeordnete Evidenz fehlt. Werden MSE hauptsächlich durch die Arbeit oder herrschende Arbeitsumgebung ausgelöst oder verschlimmert, werden diese als arbeitsbezogene MSE definiert (Kok et al., 2019). Innerhalb dieser Berufsgruppen sind es explizit die oberen Extremitäten, die vermehrt beansprucht werden durch die Interaktionen von Menschen und Maschinen oder Instrumenten. Dadurch entstehen typische Überlastungssyndrome der oberen Extremitäten wie die Tendovaginitis, die Epikondylitis oder das Karpaltunnelsyndrom, welche oft unter dem Term „*Repetitive Strain Injuries*" zusammengefasst werden (Yassi, 1997). Ein pathologisches Merkmal dieser Überlastungssyndrome ist das Missverhältnis zwischen Beanspruchung und Regenerationszeit (Aicale et al., 2018). Infolgedessen kann es zu Mikrotraumata kommen, die über die Zeit zu chronisch-degenerativen Veränderungen im Gewebe führen (ebd.). Diese Arten der Belastung finden sich ebenfalls im E-Sport wieder. Besonders von repetitiver Beanspruchung der Handgelenke (Law et al., 2023), monotonen Körperhaltungen (Franks et al., 2022) sowie von ununterbrochenen Sitzperioden wird berichtet (Migliore et al., 2021). Darüber hinaus fehlt es im E-Sport an einer systematischen Planung von Aktivitäts- und Regenerationsphasen, was Überlastungssyndrome begünstigen kann (Manci et al., 2024). Diese Faktoren sollten in einem adaptiven Belastungs-Beanspruchungsmodell berücksichtigt werden.

Bereits 1981 wurde der erste bekannte Fall von handgelenkbezogenen Überlastungssymptomen infolge exzessiven Videospielens dokumentiert, welcher als „*Space Invaders*-Handgelenk" bekannt wurde (McCowan, 1981). Neben weiteren Fallberichten (Jalink et al., 2014) gibt es bereits seit etwa 20 Jahren Querschnittserhebungen, welche auf eine mögliche Assoziation zwischen Häufigkeiten von MSE und Videospielpartizipation hinweisen (Burke & Peper, 2002; Tazawa & Okada, 2001). In der näheren Vergangenheit wurde diese Annahme durch verschiedene internationale Studien bestätigt (Hakala et al., 2006; Lindberg et al., 2020; Silva et al., 2016; Wang et al., 2019; Yabe et al., 2018). Festzuhalten ist, dass es sich dabei vorwiegend um Beobachtungsstudien handelt und nur wenige interventionelle Studien in diesem Bereich existieren. Zusätzlich fehlt es an einer systematischen Aufarbeitung der unterschiedlichen Studien und Zusammenfassung der Ergebnisse, um eine generalisierbare Aussage treffen zu können.

2.4 Anforderungs- und Belastungsprofil des E-Sports

Mit Tausenden von Athlet*innen, einer globalen Zuschauerschaft (Newzoo, 2023) und Preisgeldern in Millionenhöhe (McLeod et al., 2022) hat sich der E-Sport als wirtschaftlich und kulturell bedeutende Disziplin etabliert. Diese wachsende Bedeutung spiegelt sich auch in der Aufnahme der „*Olympic Esports Games*“ in die olympische Bewegung wider (International Olympic Committee, 2024). Ebenfalls im wissenschaftlichen Kontext gewinnt der E-Sport zunehmend an Aufmerksamkeit (Jenny et al., 2025; Wollesen et al., 2025). Mit dem wachsenden Interesse am E-Sport rücken insbesondere die Leistungsfähigkeit und die Gesundheit von E-Sport-Athlet*innen zunehmend in den Fokus von Forschung und E-Sport-Organisationen. Die Anforderungen an E-Sport-Athlet*innen wurden von Nagorsky und Wiemeyer (2020) in einem integrativen Modell der E-Sport-Leistungsfähigkeit zusammengefasst. Das Modell beschreibt die Symbiose von videospielspezifischen Kompetenzen und Faktoren für die allgemeine sportliche Leistungsfähigkeit, welche zusammen die Leistungsfähigkeit im E-Sport abbilden (Abb. 3).

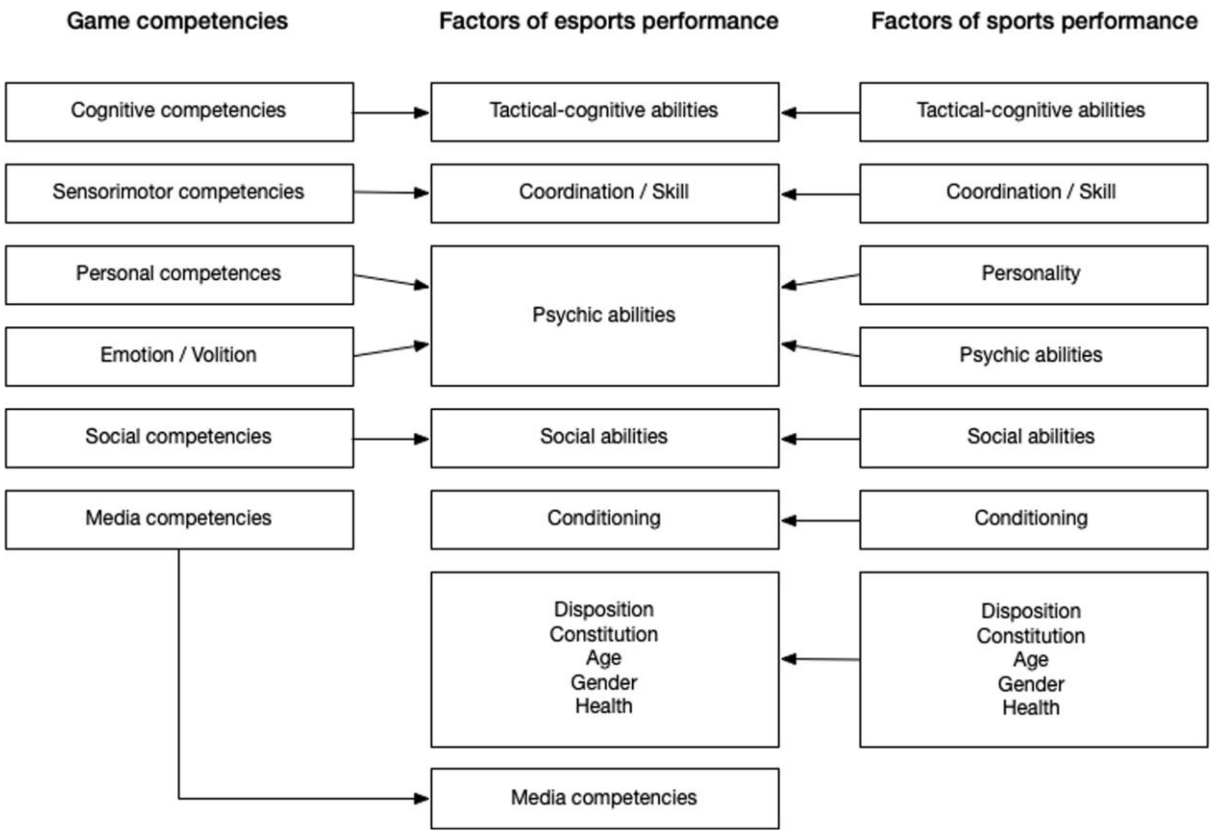

Abbildung 3: Integratives Modell der E-Sport-Leistung (nach Nagorsky & Wiemeyer, 2020, S. 7).

Die E-Sport-Leistungsfaktoren umfassen unter anderem motorische Fähigkeiten zur Steuerung der digitalen Umgebung über kognitiv-psychologische Kompetenzen für die Planung von Spielzügen bis hin zu kommunikativen Fähigkeiten für die Zusammenarbeit mit Teamkolleg*innen (Nagorsky & Wiemeyer, 2020). Die Autoren verweisen auf die Varianz der Leistungsprofile in Abhängigkeit des jeweiligen Videospielgenres oder Spieletitels. Vergleichbar ist dieser Unterschied mit verschiedenen Ausprägungen des Leistungsprofils zwischen traditionellen Sportarten. Im Mittelpunkt der E-Sport-Leistung stehen die kognitiv-psychologischen Kompetenzen, da diese den wesentlichen Anteil an der Leistungsfähigkeit ausmachen, weshalb E-Sportler*innen oft als „kognitive Athlet*innen" beschrieben werden (Campbell et al., 2018). Auf körperlicher Ebene sind es vor allem die feinmotorischen und koordinativen Fähigkeiten, die für die präzise Bedienung von Eingabegeräten zur Interaktion mit der digitalen Umgebung erforderlich sind (Dupuy et al., 2024). Die daraus resultierenden Bewegungen beschränken sich meistens auf die oberen Extremitäten, vor allem auf den Ellenbogen, das Handgelenk sowie die Finger (Law et al., 2023). Ein Leistungsparameter, welcher in diesem Zusammenhang häufig als

Beispiel dient, sind die Aktionen pro Minute (APM), welche sich aus den Tastenanschlägen der Maus und Tastatur ergeben (Migliore et al., 2021). Unterschiedliche Quellen verweisen auf bis zu 500-600 APM im Spitzenbereich (Migliore & Beckman, 2021) oder auf 200-300 APM im Durchschnitt (Mao, 2023). Je nach Spielgenre ist dieser Parameter unterschiedlich ausgeprägt und von Relevanz für den Spielverlauf sowie für den Sieg oder die Niederlage (Jenny et al., 2025). Andere übergeordnete körperliche Leistungsfaktoren sind in der aktuellen Studienlage ungenügend beschrieben. Einzelne Studien verweisen auf den potenziellen Nutzen konditioneller Leistungsfaktoren (McNulty et al., 2023). Regelmäßiges körperliches Training ist assoziiert mit positiven strukturellen Veränderungen des Gehirns, erhöhten exekutiven Funktionen sowie einer Steigerung der mentalen Resilienz (Stillman et al., 2020). Diese Anpassungen können für E-Sportler*innen, welche täglich mehrstündigen Videospielexpositionen ausgesetzt sind, von wesentlicher Bedeutung sein. Daneben ist bekannt, dass spezifische Kräftigungs- und Dehnübungen das Risiko für Überlastungssyndrome, wie beispielsweise einer Epikondylitis, reduzieren können (Stephenson et al., 2021). Jedoch werden diese Annahmen häufig aus physiologischen Überlegungen oder fachfremden Studien abgeleitet und nicht explizit durch Studien mit E-Sportler*innen nachgewiesen.

Aufgrund der genannten Anforderungen sind E-Sportler*innen einer Vielzahl von biopsychosozialen Stressoren ausgesetzt, wie hohem mentalem Druck oder sozialen Spannungen innerhalb des Teams (Leis et al., 2022). Auf Dauer und ohne geeignete Ressourcen können solche Stresszustände zu psychophysiologischen Reaktionen und Überlastungen führen (Leis & Lautenbach, 2020). Im Gegensatz zu den komplexen kognitiven Anforderungen steht die einseitige und monotone körperliche Belastung. In seiner jetzigen Form wird E-Sport überwiegend in sitzender Position ausgeführt (McNulty et al., 2023), wodurch Trainings- und Sitzzeiten von bis zu 13 Stunden pro Tag möglich sind (Manci et al., 2024). Zusätzlich zu den täglichen Trainingsbelastungen kommen Turniere hinzu, bei denen mehrere Wettkämpfe an einem Tag ausgetragen werden, beispielsweise im Format „*Best-of-Three*" (d. h. ein Sieg erfordert zwei gewonnene Spielrunden) (ESL Gaming GmbH, 2024; Riot Games, 2024). Je nach E-Sport-Titel und Leistungsniveau der E-Sportler*innen, variiert die Dauer einer einzelnen Spielrunde zwischen 20 und 90 Minuten, sodass ein einzelner Wettkampf im *Best-of-Three*-Modus bis zu drei Stunden in Anspruch nehmen kann

(British Esports Association, 2021). Die Pausen zwischen den Spielrunden sind abhängig vom Turnierveranstalter und betragen im Durchschnitt zwischen 5 und 15 Minuten (ESL Gaming GmbH, 2024; Riot Games, 2024). Werden mehrere solcher Wettkämpfe an einem oder über mehrere aufeinanderfolgende Tage ausgetragen, resultieren daraus erhebliche physische Belastungen, insbesondere für das muskuloskelettale System.

Umfragen deuten darauf hin, dass der Großteil der deutschen Videospielenden und E-Sportler*innen sich ausreichend körperlich bewegt und die Mindestanforderungen der Weltgesundheitsorganisation (WHO) erfüllt (Rudolf et al., 2020; Soffner et al., 2023). Demgegenüber stehen die Ergebnisse einer internationalen Studie, welche Fragebogen- und Akzelerometerdaten von E-Sportler*innen miteinander verglichen hat (Nicholson et al., 2024). Zwar wiesen die Selbstauskünfte auf ein hohes Maß an körperlicher Aktivität hin, jedoch widersprachen die objektiven Messungen in einer Teilstichprobe dieser Einschätzung. Abhängig von der Auswertungsmethode wurde die moderate körperliche Aktivität pro Tag im Median um 15 bis 26 Minuten überschätzt. Bei den metabolischen Äquivalent-Minuten pro Woche zeigte sich eine Überschätzung um 73 % bis 416 % (Nicholson et al., 2024). Ein weiterer kontrovers diskutierter Aspekt ist das Körpergewicht bzw. der Body Mass Index (BMI) von E-Sporlter*innen im Vergleich zur Körperkomposition. In Befragungen von deutschen Videospielenden und E-Sportler*innen mit jeweils 800-1000 Befragten, wiesen die Teilnehmenden im Durchschnitt einen BMI im normalgewichtigen Bereich (20-24,9 kg/m²) auf, mit leichter Tendenz zum Übergewicht (Rudolf et al., 2020; Rudolf et al., 2022; Soffner et al., 2023). Betrachtet man die Körperkomposition von E-Sportler*innen, gibt es Hinweise darauf, dass trotz eines BMI im Normbereich, der Fettmasseanteil höher und die Magermasse sowie Mineraldichte der Knochen geringer ausfällt als bei einer gleichaltrigen Vergleichsgruppe (DiFrancisco-Donoghue et al., 2020). Demzufolge könnten längere muskuläre Belastungsperioden aufgrund fehlender physiologischer Ressourcen schneller zu Überlastungserscheinungen führen.

Die Bewegungen im E-Sport werden von den oberen Extremitäten dominiert, da diese hauptsächlich für die Interaktion mit der virtuellen Umgebung benötigt werden. Die Bewegungsmuster werden als repetitiv, irregulär und asymmetrisch beschrieben, da die Arme häufig unterschiedliche Bewegungen zeitgleich ausführen müssen (Dupuy et al., 2024). Laut Autoren bergen solche Bewegungsmuster kurzfristig die Gefahr von muskulärer Ermüdung und langfristig erhöhen sie das Risiko für MSE. Trotz der wachsenden Bedeutung des E-Sports existieren bislang nur wenige Untersuchungen zur muskulären Ermüdung in diesem Kontext. Aus diesem Grund werden ebenfalls Studien herangezogen, die sich mit dem nicht-kompetitive Videospielen befassen, um mögliche Konsequenzen für den E-Sport daraus abzuleiten. Erste Studien deuten darauf hin, dass bereits nach 20- bis 30-minütigem Spielen am Smartphone muskuläre Ermüdungserscheinungen an der Rücken- (Hanphitakphong et al., 2021) und Daumenmuskulatur (Wang et al., 2019) bei nicht-videospielenden Personen auftreten können. Im Kontrast dazu führte ein einstündiges, videospielspezifisches Fatigueprotokoll weder bei videospielenden noch bei nicht-videospielenden Personen zu signifikanten Ermüdungserscheinungen der Handgelenksextensoren (Forman et al., 2024). Dennoch folgern die Autoren, dass aufgrund der erhöhten elektrischen Aktivität der Handgelenksextensoren im Verlauf der Untersuchung Überlastungserscheinungen schneller auftreten könnten. Daneben ist bekannt, dass kontinuierliche Computerarbeit die muskuläre Ermüdung erhöhen kann (Callegari et al., 2018; Ding et al., 2020). In der Konsequenz könnte eine vermehrte Partizipation im E-Sport zu erhöhter muskulärer Ermüdung führen.

Gemäß dem Belastungs-Beanspruchungskonzept (vgl. Kap. 2.2) könnten sich daraus zwei theoretische Konsequenzen ableiten:

(I) Eine verringerte körperliche Aktivität in Kombination mit hohen Sitzzeiten kann zu einer Unterforderung verschiedener anatomischer Strukturen führen, was potenziell eine Atrophie sowohl aktiver als auch passiver Gewebeanteile zur Folge hat (Wisdom et al., 2015). Solche strukturellen Veränderungen können langfristig Schmerzen begünstigen und das Risiko für MSE erhöhen (Gallagher, 2022). Darüber hinaus kann die daraus resultierende Abnahme funktioneller Ressourcen zu einer geringeren Belastungstoleranz führen, ein Zustand, der im Sinne des Belastungs-Beanspruchungskonzepts das Risiko für Überlastung erhöht.

(II) Durch anhaltende, repetitive Bewegungen der oberen Extremitäten bei unzureichender Regeneration können sich mikrotraumatische Prozesse entwickeln, insbesondere an den Sehnenansätzen (Aicale et al., 2018; Millar et al., 2021). Langfristig kann dies zur Entstehung von Überlastungssyndromen in Hand-, Ellenbogen- oder Schultergelenken führen.

Abbildung 4 veranschaulicht diesen pathophysiologischen Prozess in Anlehnung an das Belastungs-Beanspruchungskonzept nach Rohmert (1984), exemplarisch dargestellt am Beispiel des Videospielens bzw. des E-Sports.

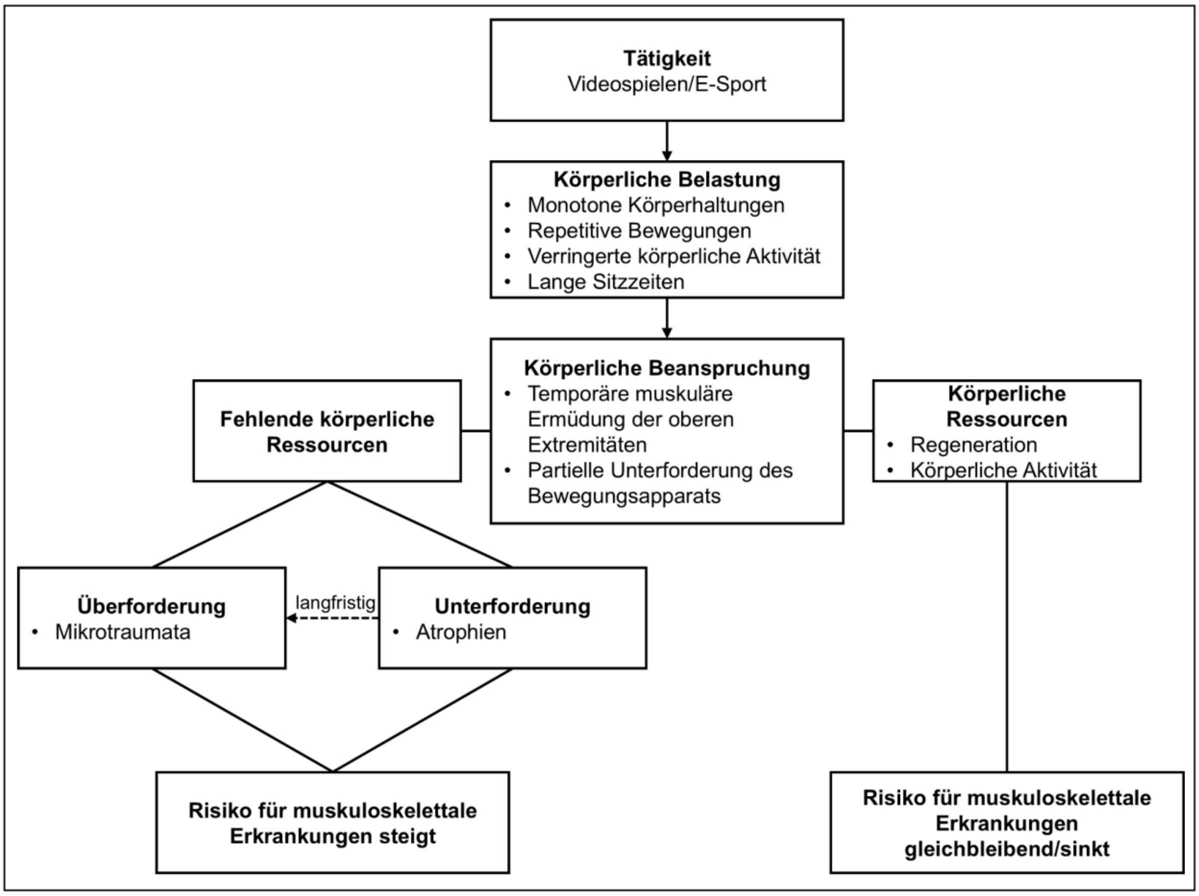

Abbildung 4: Adaptiertes Belastungs-Beanspruchungskonzept (eigene Darstellung).

Gemäß diesem theoretischen Modell wäre es wichtig zu eruieren, ob die vorherrschenden Belastungen tatsächlich zu einem erhöhten Risiko von MSE beim kompetitiven Videospielen führen und welche spezifischen Belastungsgrößen erhoben werden können. Durch die beschriebenen repetitiven Anforderungen könnte auf der physischen Ebene die muskuläre Ermüdung eine tragende Rolle spielen (Dupuy et al., 2024). Allerdings bestehen hinsichtlich der Beschreibung der vorherrschenden physischen Belastungen und Beanspruchungen im E-Sport noch erhebliche Forschungslücken (Dupuy et al., 2024).

3. Forschungsfragen

Aus den zuvor dargestellten theoretischen Überlegungen zu den Belastungen und den daraus resultierenden Beanspruchungen im E-Sport ergibt sich für die vorliegende Arbeit folgende Hauptfragestellung:

Welche negativen Einflüsse hat das kompetitive Videospielen auf die muskuloskelettale Beanspruchung von E-Sportler*innen und welche kurzfristigen sowie potenziell langfristigen Folgen lassen sich daraus ableiten?

Zur Beantwortung der Hauptfragestellung sollen nachfolgende drei Teilfragestellungen eruiert werden:

I. Inwieweit wird das Muskel-Skelett-System durch eine erhöhte Videospielexposition negativ beeinflusst?

II. Verändert sich die muskuloskelettale Beanspruchung von E-Sportler*innen, während des kompetitiven Videospielens über mehrere Stunden?

III. Gibt es Unterschiede zwischen subjektiven und objektiven Beanspruchungsparametern von E-Sportler*innen während des kompetitiven Videospielens?

4. Studie I: Muskel-Skelett-Erkrankungen bei Videospielenden

Referenz:

Tholl, C., Bickmann, P., Wechsler, K., Froböse, I. & Grieben, C. (2022). Musculoskeletal disorders in video gamers - a systematic review. *BMC musculoskeletal disorders*, *23*(1), 678. https://doi.org/10.1186/s12891-022-05614-0

Abstract:

Background: Video gaming is a recreational activity with yearly increasing popularity. It is mostly a sedentary behavior combined with repetitive movements of the upper limbs. If performed excessively, these movements may promote strain injuries and a sedentary lifestyle is one of the contributing factors to musculoskeletal disorders. Therefore, a systematic review was conducted to evaluate if video gaming negatively affects the musculoskeletal system of video gamers.

Methods: PubMed, Web of Science and The Cochrane Library were systematically searched in order to identify relevant peer reviewed original articles in English published between 2000 and 2021. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was used for the analysis. Studies were included when they contained investigations of changes of the musculoskeletal system due to video gaming in healthy individuals. Studies with participants older than 60 years or solely psychological, social or cardiovascular outcomes were excluded. An adapted version of the Newcastle-Ottawa Scale was used for the risk of bias analysis.

Results: Sixteen observational studies involving a total of 62,987 participants met the inclusion criteria. A majority (11) of the studies reported statistical negative musculoskeletal changes due to video game playtime. Four studies did not report changes and one study found no effect of video game playtime on the musculoskeletal system. Out of the eleven studies, which demonstrated a negative impact of video game playtime on the musculoskeletal system, the most reported painful body parts were the neck (n = 4), shoulder (n = 4) and back (n = 3). Ten studies reported odds ratios (OR) for the dependence of the appearance of musculoskeletal disorders on video game playtime. In eight studies OR were significantly increased (1.3-5.2).

Conclusion: Eleven out of twelve studies demonstrated a negative impact of video game playtime on the musculoskeletal system. In particular, excessive video game playtimes (> 3 h/day) seemed to be a predictor for the appearance of musculoskeletal disorders. Due to their great popularity across multiple generations, specific and tailored prevention and health promotion programs for video gamers need to be developed to counteract this important public health issue.

Keywords: Video gaming, MSD, Sedentary behavior, Physical pain, Esports

5. Studie II: Subjektive Beanspruchung im E-Sport

Referenz:

Tholl, C., Soffner, M. & Froböse, I. (2024). How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming. *Frontiers in sports and active living*, *6*, 1370485. https://doi.org/10.3389/fspor.2024.1370485

Abstract:

Introduction: Esports or competitive video gaming is a rapidly growing sector and an integral part of today's (youth) culture. Esports athletes are exposed to a variety of burdens, that can potentially impact an athlete's health and performance. Therefore, it is important that esports athletes are aware of (physical) burden and exertion associated with esports. For this purpose, a study was conducted to evaluate the influence of competitive video gaming on the perceived physical exertion and the perceived physical state (PEPS).

Methods: Thirty-two healthy male esports athletes participated in two competitive video gaming sessions lasting 90-120 min, interrupted by a 10-minute passive sitting break. Repeated measures of perceived physical exertion (Borg Categorial Ratio-10 scale) and perceived physical state were recorded before, during, and after each video game session. Repeated measures ANOVA and Friedman's test were used for statistical analysis.

Results: The results showed a significant difference in all dimensions of the PEPS ($p < 0.05$) as well as in Borg scale ($p < 0.001$). Post-hoc tests revealed significant increases in Borg scale between baseline measurements (T0: 1.0 ± 1.0) and after the first competitive video gaming session (T1: 2.4 ± 1.3, $p < 0.001$), as well as after the second competitive video gaming session (T3: 3.0 ± 1.7, $p < 0.001$). Furthermore, there was a significant reduction in perceived exertion between the measurement time after the first competitive video gaming session (T1) and the break (T2: 1.3 ± 1.2, $p < 0.001$). The PEPS dimensions activation, trained, and mobility showed similar significant changes in post-hoc analysis.

Discussion: The results indicate that the perceived physical burden significantly increases during esports participation. As the duration of competitive video gaming extends, the perceived physical state decreases and perceived physical exertion increases. A passive break between two video game sessions can at least partially restore physical exertion and physical state. However, this break neither returns the scores to their baseline levels nor prevents a further decline in scores during the second video game session. Over time and with a lack of observation, this could result in health and performance limitations.

Keywords: video games, RPE, sedentary behavior, ANOVA, fatigue, rest

6. Studie III: Objektive Belastung und Beanspruchung im E-Sport

Referenz:

Tholl, C., Hansen, L., & Froböse, I. (2025). Wrist extensor fatigue and game-genre-specific kinematic changes in esports athletes: a quasi-experimental study. *BMC sports science, medicine & rehabilitation*, 17(1), 261. https://doi.org/10.1186/s13102-025-01305-0

Abstract:

Background: Muscular fatigue critically affects health, performance, and safety in daily activities and sports. Esports or competitive gaming involves prolonged sitting and repetitive upper extremity movements, increasing the risk of muscular fatigue. Sustained activity may contribute to long-term musculoskeletal disorders (MSD). Despite this risk, biomechanical analyses in esports remain limited. This study examines muscular fatigue and wrist kinematics in esports athletes across different video game genres.

Methods: Thirty-two healthy male esports athletes (23.8 ± 3.4 years) participated in two 90–120-minute competitive video gaming sessions, separated by a 10-minute passive sitting break. Surface electromyography (EMG) of the upper trapezius and wrist extensors, as well as wrist kinematics, were recorded. The median frequency (MDF) and root mean square (RMS) were used to quantify muscular fatigue. Statistical analyses included mixed ANOVA, one-way repeated measures ANOVA, and robust ANOVA with Bonferroni correction.

Results: Repeated measures ANOVA indicated significant decreases in the MDF and RMS of the wrist extensors over time ($p < 0.001$). For the upper trapezius, only the right-side MDF showed a significant decrease over time; however, post-hoc analysis did not confirm this effect. Mixed ANOVA revealed no interaction between time and video game genre on kinematic data. First-person shooter players exhibited significantly greater cumulative distances ($p = 0.006$) and velocity zero-crossings ($p = 0.043$) than multiplayer online battle arena players in robust ANOVA.

Conclusions: The findings indicate a progressive increase in wrist extensor fatigue over time, whereas wrist kinematics vary by video game genre but remain unaffected by time. The lack of neuromuscular recovery post-break suggests the potential for cumulative muscular fatigue. These repetitive loads could increase the risk of MSD. Therefore, implementing preventive training strategies and regular active breaks may help mitigate these effects in esports athletes.

Keywords: video games, overuse syndrome, biomechanics, motion capture, screen-based activity, physical demands

7. Diskussion

Ziel der vorliegenden Dissertation war es herauszustellen, inwieweit das kompetitive Spielen von Videospielen das muskuloskelettale System beeinflusst und konkrete körperliche Belastungs- und Beanspruchungsfaktoren im E-Sport zu untersuchen. Die in dieser Arbeit präsentierten Studien stützen die Annahme, dass ein erhöhter Videospielkonsum mit einem gesteigerten Auftreten von MSE assoziiert ist. Darüber hinaus konnten erstmals unter realitätsnahen Bedingungen die körperlichen Belastungen und die daraus resultierenden Beanspruchungen im E-Sport aufgezeigt werden. Besonders hervorzuheben ist, dass sich sowohl subjektive als auch objektive Beanspruchungsparameter über längere Spielzeiten hinweg nachteilig verändern.

7.1 Ergebnisdiskussion

7.1.1 Negative Assoziationen zwischen Videospielexposition und dem muskuloskelettalen System (Fragestellung I)

Um der Fragestellung nachzugehen, inwieweit das Videospielen das Muskel-Skelett-System negativ beeinflusst, wurde zunächst eine systematische Literaturübersicht erstellt (Studie I). Basierend auf den analysierten Studien besteht eine positive Assoziation zwischen der Videospielzeit und dem Auftreten muskuloskelettaler Beschwerden. Insbesondere war eine tägliche Videospielzeit von mehr als drei Stunden mit einem bis zu 5,2-fach erhöhten Chancenverhältnis (*Odds Ratio*) für das Auftreten von MSE assoziiert. Dabei waren die am häufigsten betroffenen anatomischen Regionen der Schulter-Nacken-Bereich, der (untere) Rücken sowie die Hände und Handgelenke. Die Qualität der Studien war überwiegend hoch, mit einem geringen bis moderaten Risiko für Verzerrungen. Dabei ist zu berücksichtigen, dass der Großteil der Studien Querschnittsanalysen darstellt, was die Möglichkeit zur Ableitung kausaler Zusammenhänge einschränkt.

Um dieser Limitation zu begegnen und potenzielle Belastungs- und Beanspruchungsfaktoren im E-Sport vertieft zu untersuchen, wurde eine quasi-experimentelle Untersuchung konzipiert. Die Ergebnisse dieser Untersuchung (Studie II & III) stützen den in Studie I identifizierten Zusammenhang: Über die Dauer einer längeren Videospielexposition zeigte sich eine signifikante Zunahme der körperlichen Beanspruchung. Dies unterstreicht, dass bereits eine einmalige Belastungsexposition messbare negative Auswirkungen auf die körperliche Beanspruchung haben kann. Über längere Zeiträume und ohne passende Gegenmaßnahmen, kann dies das Risiko für MSE erhöhen. Ebenso konnte in Studie II gezeigt werden, dass die eingeschlossenen E-Sportler eine Jahresprävalenz für Nackenschmerzen von 50 % und für Rücken- sowie Handgelenksschmerzen von etwa 30 % aufwiesen.

Diese Erkenntnisse stehen im Einklang mit aktuellen internationalen Befragungen, die eine hohe Prävalenz muskuloskelettaler Beschwerden unter E-Sportler*innen unterschiedlicher Leistungsniveaus belegen (Ekefjärd et al., 2024; Fathuldeen et al., 2023; Monma et al., 2024). Die beschriebenen Prävalenzraten liegen zwischen 30 % und 60 %, abhängig vom Leistungsniveau, der wöchentlichen Spielzeit und der jeweils betrachteten Körperregion. Kritisch zu betrachten ist hierbei, dass lediglich die Studie von Ekefjärd et al. (2024) validierte Erhebungsinstrumente verwendete, während die übrigen Studien auf nicht-validierte Items zurückgriffen (Fathuldeen et al., 2023; Monma et al., 2024).

Vergleicht man die Daten mit Prävalenzraten unter Büroarbeitenden, werden Parallelen deutlich: Verschiedene Studien berichten von einer 12-Monats-Prävalenz für Nackenschmerz von 32 % bis zu 60 % (Holzgreve et al., 2021; Kaya Aytutuldu et al., 2022), für lumbalen Rückenschmerz von etwa 25 % bis 72 % (Kaya Aytutuldu et al., 2022; Mohammadipour et al., 2018) und für Handgelenksschmerz von 15 % bis etwa 37 % (AlOmar et al., 2021; Holzgreve et al., 2021). Demnach ist die 12-Monats-Prävalenz bei E-Sportler*innen und Büroarbeitenden vergleichbar. Allerdings ist das signifikant niedrigere Durchschnittsalter der E-Sport-Populationen hervorzuheben. Während die untersuchten Büroarbeitenden ein mittleres Alter von 31 bis 44 Jahren aufweisen (AlOmar et al., 2021; Holzgreve et al., 2021; Kaya Aytutuldu et al., 2022), liegt dieses bei E-Sportler*innen zwischen 18 und 24 Jahren (Ekefjärd et al., 2024; Fathuldeen et al., 2023; Monma et al., 2024). Dies deutet darauf hin, dass E-Sportler*innen möglicherweise bereits in jungen Jahren gesundheitliche Beschwerden entwickeln. In der Folge könnten sie das Gesundheitssystem frühzeitig belasten und ein erhöhtes Risiko für die Chronifizierung dieser Beschwerden aufweisen. Langfristig könnte dies negative Auswirkungen auf die Erwerbsfähigkeit der Betroffenen haben. Ein möglicher Erklärungsansatz hierfür liegt in der höheren

Intensität und Frequenz physischer Belastungen im professionellen E-Sport im Vergleich zur Büroarbeit, die zu einer stärkeren Beanspruchung des Muskel-Skelett-Systems führen kann (vgl. Kap. 2.3).

Zu beachten ist, dass muskuloskelettale Erkrankungen nicht ausschließlich durch physische Belastungen verursacht werden, sondern ein komplexes, multifaktorielles Konstrukt darstellen (vgl. 2.3). Insbesondere psychosoziale Stressoren könnten einen wesentlichen Einfluss auf das Risiko für MSE im E-Sport haben (Kok et al., 2019). Professionelle E-Sportler*innen berichten von erhöhtem Leistungsdruck, zwischenmenschlichen Konflikten im Team sowie externen Stressoren wie Zuschauererwartungen, die eine mentale Belastung darstellen (Leis et al., 2022). Darüber hinaus können ökonomische Unsicherheiten, bedingt durch befristete Verträge oder niedrige Gehälter, zusätzlichen psychischen Stress erzeugen (Hupke et al., 2022; Rothe et al., 2017) und dadurch das Risiko für MSE erhöhen. Solche prekären Beschäftigungsverhältnisse sind im E-Sport häufig zu beobachten (Smith, 2022). Angesichts dieser Erkenntnisse sollten zukünftige Studien neben körperlich-ergonomischen auch psychosoziale und ökonomische Einflussfaktoren systematisch untersuchen, um die Entstehung muskuloskelettaler Beschwerden im E-Sport ganzheitlich zu erfassen. Diese Faktoren sollten zudem in einem adaptiven Belastungs-Beanspruchungsmodell des E-Sports berücksichtigt werden, um ein umfassenderes Verständnis der Belastungsmechanismen zu ermöglichen.

Zusammenfassend bestätigen die im Rahmen dieser Dissertation vorgestellten Studien die bestehende Forschungslage und stützen die Hypothese, dass ein erhöhter Videospielkonsum mit nachteiligen Effekten auf das Muskel-Skelett-System verbunden sein kann. Insbesondere bei unzureichenden kompensatorischen Ressourcen, wie eingeschränkter Regeneration und mangelnder körperlicher Aktivität, könnten sich diese Belastungen möglicherweise langfristig negativ auf die muskuloskelettale Gesundheit auswirken (vgl. Kap. 2.3).

7.1.2 Veränderung der muskuloskelettalen Beanspruchung während kompetitiven Videospielens (Fragestellung II)

Im Rahmen der zweiten Fragestellung wurde eine Untersuchung durchgeführt, die sich unter anderem mit der muskulären Ermüdung des Musculus trapezius pars descendens (*Trapezius*) und des Musculus extensor digitorum (*Handgelenksextensoren*) sowie mit kinematischen Parametern der Maushand befasste (Studie III). Die Ergebnisse zeigen, dass die muskuläre Ermüdung nach zwei aufeinanderfolgenden Videospieleinheiten von jeweils 90 bis 120 Minuten nur bei den Handgelenksextensoren signifikant anstieg. Im Gegensatz dazu blieben die kinematischen Daten der Maushand über die Spielzeit hinweg unverändert. Es ist hervorzuheben, dass eine zehnminütige Pause zwischen den Videospieleinheiten keinen signifikanten Einfluss auf die objektiv erhobenen Parameter hatte. Somit steigt die muskuloskelettale Beanspruchung partiell während des kompetitiven Videospielens über mehrere Stunden bei gleichbleibender kinematischer Belastung.

Diese Ergebnisse decken sich mit den Befunden experimenteller Studien, die ebenfalls einen Anstieg der muskulären Ermüdung infolge von Videospielpartizipation nachweisen konnten (Hanphitakphong et al., 2021; Wang et al., 2019). Allerdings unterscheiden sich diese Studien in mehreren wesentlichen Aspekten von der hier vorgestellten Untersuchung (Studie II & III), insbesondere hinsichtlich der Spieldauer, des verwendeten Endgeräts sowie der untersuchten Muskelgruppen. Beide Studien beziehen sich auf nicht-videospielende Personen, die über einen kurzen Zeitraum von 20 bzw. 30 Minuten mit einem Smartphone spielten. Die Arbeitsgruppe um Hanphitakphong et al. (2021) analysierte die Ermüdung der Rückenmuskulatur nach 20-minütiger Smartphone-Nutzung, während Wang et al. (2019) die muskuläre Ermüdung im Bereich der Daumenmuskulatur nach einer 30-minütigen Nutzung untersuchte. Trotz der Unterschiede in Versuchsaufbau und Zielgruppe ist hervorzuheben, dass in allen genannten Studien, einschließlich der hier vorgestellten Untersuchung, die Medianfrequenzanalyse als Methode zur Erfassung muskulärer Ermüdung verwendet wurde. Diese methodische Übereinstimmung ermöglicht eine bessere Vergleichbarkeit der Ergebnisse auf physiologischer Ebene. Im Gegensatz dazu berichten Forman et al. (2024), dass ein einstündiges, videospielspezifisches Fatigueprotokoll keine signifikanten Veränderungen der Frequenzparameter der Handgelenksextensoren hervorruft, weder bei videospielenden noch bei nicht-videospielenden Personen. Dennoch berichteten die Autor*innen über eine kontinuierlich zunehmende elektrische Aktivität der betroffenen Muskulatur im Verlauf der Belastung, was als möglicher Hinweis auf beginnende Überlastungsprozesse interpretiert wurde. Mögliche Ursachen für die unterschiedlichen Befunde zwischen den Studien könnten in der längeren Dauer, der unterschiedlichen Aufgabenstellung sowie der spezifischeren Zielgruppe liegen, was die Übertragbarkeit früherer Studienergebnisse auf den E-Sport nur eingeschränkt möglich macht. Im Vergleich dazu weist die hier vorgestellte Untersuchung (Studie II & III) deutlich längere Spielzeiten auf, die unter realitätsnäheren, kompetitiven Bedingungen durchgeführt wurden. Darüber hinaus liegt der der Fokus auf semi-professionellen bis professionellen E-Sportler*innen, bei denen aufgrund der repetitiven Belastung von einer insgesamt höheren körperlichen Beanspruchung auszugehen ist.

Muskuläre Ermüdung wird dabei als ein wesentlicher Risikofaktor angesehen, der langfristig zur Entstehung muskuloskelettaler Beschwerden im E-Sport und bei exzessiver Videospielexposition beitragen könnte (Dupuy et al., 2024). Kumulative biomechanische Ermüdungsprozesse gelten in diesem Zusammenhang als zentrale Ursache für die Entwicklung von MSE (Gallagher & Schall, 2017). Auf zellulärer Ebene wird angenommen, dass wiederholte mechanische Belastung zu Mikroschäden in unterschiedlichen Gewebearten führen kann. Tierexperimentelle Studien zeigen, dass sowohl mit zunehmender Belastungsintensität als auch mit steigender Repetition pathophysiologische Veränderungen im untersuchten Gewebe auftreten können (Barbe et al., 2013; Geronilla et al., 2003; Willems & Stauber, 2000). Dabei scheint insbesondere die Kombination aus hoher Intensität und hoher Wiederholungszahl das Risiko für Gewebeschäden signifikant zu erhöhen. Barbe et al. (2013) weisen darüber hinaus darauf hin, dass selbst repetitive Belastungen innerhalb physiologischer Grenzen langfristig zu strukturellen Schäden führen können. In-vitro-Studien mit humanem Sehnenzellmaterial bestätigen diesen Zusammenhang und zeigen, dass repetitive mechanische Reize inflammatorische sowie degenerative Signalkaskaden in der beanspruchten Sehnenstruktur aktivieren können (Li et al., 2004; Mousavizadeh et al., 2024). Zudem steigt die Anzahl von Immunzellen, die unter physiologischen Bedingungen nur in geringer Zahl in gesunden Sehnengeweben vorkommen (Mousavizadeh et al., 2024). Eine aktuelle systematische Übersichtsarbeit bestätigt den Zusammenhang zwischen submaximalen, repetitiven Belastungen und dem Vorkommen ermüdungsbedingter Sehnen- oder Muskelverletzungen (Vila Pouca et al., 2021). Die Autor*innen kommen zu dem Schluss, dass nur ein geringer Anteil der Verletzungen, wie Sehnenabrisse, auf einmalige traumatische Ereignisse zurückzuführen sind. Der überwiegende Teil, insbesondere bei trainierten

Sportler*innen, entsteht vermutlich durch die Akkumulation mikroskopischer Ermüdungsschäden (ebd.). Diese Ergebnisse verdeutlichen, dass nicht nur Überbelastung, sondern auch eine unzureichende Regeneration bei wiederholter Beanspruchung ein potenzielles Risiko für strukturelle Gewebeschäden darstellen kann. Somit stützen diese Befunde das in Kapitel 2.4 adaptierte Belastungs-Beanspruchungskonzept im Kontext des E-Sports.

Vor dem Hintergrund dieser Befunde wird die zentrale Rolle ausreichender Erholung und Regeneration im E-Sport deutlich, sowohl im kurzfristigen Sinne (Erholung zwischen Spieleinheiten) als auch langfristig im Hinblick auf die Belastungstoleranz des muskuloskelettalen Systems. Diese Annahme deckt sich mit den Ergebnissen der Studie III: Eine zehnminütige passive Pause reichte nicht aus, um muskuläre Ermüdung effektiv zu kompensieren oder biomechanische Anpassungsreaktionen signifikant zu beeinflussen. In Anbetracht der Videospielzeitdauer und Belastungsintensität erscheint es daher notwendig, längere oder aktiv gestaltete Pausenformate zu prüfen, um potenzielle Überlastungen im E-Sport nachhaltig zu reduzieren. Für sitzende Berufsgruppen gibt es bereits Hinweise darauf, dass aktive Pausen gegenüber passiven effektiver sind, obwohl beide Varianten die muskuläre Ermüdung im Trapezius und Musculus latissimus dorsi (*Latissimus*) verringern konnten (Ding et al., 2020). Die Autor*innen kommen dabei zu dem Ergebnis, dass eine fünfminütige aktive Pause die untersuchten Muskelgruppen am längsten vor erneuter muskulärer Ermüdung bewahrt. Im Kontext des E-Sports liegen bislang nur wenige Studien vor, die sich überhaupt mit unterschiedlichen Pausengestaltungen zwischen Videospieleinheiten auseinandersetzen. Diese konzentrieren sich bislang ausschließlich auf den Einfluss akuter körperlicher Aktivität auf die kognitive Leistungsfähigkeit oder videospielspezifische Parameter (DiFrancisco-Donoghue et al., 2021; Las Heras et al., 2020; Mancı et al., 2024; Rightmire et al., 2024). Der Einfluss verschiedener Pausenarten auf muskuloskelettale Belastungs- und Beanspruchungsparameter wurde bislang nicht untersucht. Dennoch weisen die genannten Studien darauf hin, dass aktive Pausen auch positive gesundheitliche Effekte mit sich bringen könnten, ein Aspekt, der zuletzt von Manci et al. (2024) in einer Übersicht zusammengefasst wurde.

Resümierend lässt sich festhalten, dass sich die muskuloskelettale Beanspruchung von E-Sportler*innen mit zunehmender Videospielzeit und unzureichender

Regeneration deutlich erhöht. Daraus ergibt sich die Notwendigkeit, sowohl kurzfristige als auch langfristige Maßnahmen zur Belastungssteuerung und Prävention zu entwickeln, um einer Überlastung gezielt entgegenzuwirken.

7.1.3 Unterschiede zwischen subjektiven und objektiven Beanspruchungsparametern (Fragestellung III)

Zur Beantwortung der dritten Fragestellung wurden die Ergebnisse aus Studie II & III herangezogen. Wie im vorherigen Kapitel beschrieben, zeigte sich in Studie III ein signifikanter Anstieg der muskulären Ermüdung in den Handgelenksextensoren über die Dauer der Videospielbelastung. Eine zehnminütige passive Pause hatte dabei keinen messbaren Einfluss auf den objektiv erfassten Beanspruchungsparameter. In Studie II zeigte sich ein signifikanter Anstieg der subjektiv wahrgenommenen körperlichen Beanspruchung (Borg-Skala), während sich die körperliche Befindlichkeit gemäß der WKV-Skala im Verlauf der Videospieleinheiten signifikant verschlechterte. Im Unterschied zur muskulären Ermüdung, führte die zehnminütige Pause zu einer deutlichen Reduktion der subjektiven Beanspruchungsparameter, mit Ausnahme der WKV-Dimension „Gesundheit“. Diese Ergebnisse deuten auf eine Übereinstimmung der Parameter im zeitlichen Verlauf hin, zeigen jedoch eine deutliche Diskrepanz in der Reaktion auf die Pause. Während sich die subjektiven Parameter signifikant erholten in der Regenerationsphase, blieben objektive Parameter unverändert, was auf eine mögliche Wahrnehmungsanpassung/-verzerrung trotz physiologischer Belastung hindeuten könnte (Giles et al., 2018).

Diese Divergenz kann unter anderem durch kognitive Prozesse erklärt werden, welche die Wahrnehmung von Anstrengung durch Ermüdung modulieren. Ein Hinweis darauf gibt eine systematische Literaturanalyse, die untersucht hat, inwieweit mentale Ermüdung die Leistungsfähigkeit beeinträchtigt (van Cutsem et al., 2017). Die Autor*innen stellen heraus, dass insbesondere die wahrgenommene Anstrengung bei Ausdauertestungen durch voranschreitende mentale Ermüdung beeinflusst wird. Damit kann die mentale Ermüdung einen negativen Einfluss auf die wahrgenommene Anstrengung haben und leistungslimitierend wirken (ebd.). Im Kontrast dazu stehen Ergebnisse einer Metaanalyse, welche den kausalen Zusammenhang aufgrund fehlender Evidenz und hoher Verzerrungseffekte nicht nachweisen konnte (Holgado et al., 2023). Jedoch schließen die Autor*innen diesen Effekt nicht komplett aus und verweisen auf mögliche, weitere Einflüsse durch kognitive Prozesse. Pageaux (2016) hebt hervor, dass nicht nur mentale, sondern auch die subjektive körperliche Ermüdung zu einer Erhöhung der Anstrengungswahrnehmung führen kann und zeigte in früheren Untersuchungen, dass dies unabhängig von einer zentralen oder peripheren muskulären Ermüdung geschieht (Pageaux et al., 2015).

Bezogen auf die vorliegende Fragestellung III lässt sich ableiten, dass die fortschreitende muskuläre Ermüdung während des kompetitiven Videospielens mit einer gleichzeitigen Anpassung der subjektiven Beanspruchungswahrnehmung einhergeht, sodass sowohl subjektive als auch objektive Beanspruchungsparameter im Verlauf ansteigen. Die divergenten Ergebnisse durch die Pause könnten dagegen aufgetreten sein, aufgrund einer Vermischung der mentalen und körperlichen Beanspruchung. Zwar wurde während der Erhebung explizit nach der körperlichen Anstrengung gefragt, jedoch ist nicht auszuschließen, dass die Probanden ebenfalls ihre mentale Anstrengung miteinfließen lassen haben. Demgegenüber könnte die Annahme stehen, dass die erhobenen Muskelgruppen, vor allem die Handgelenksextensoren, schlecht oder gar nicht von den E-Sportler*innen wahrgenommen werden oder stressinduzierte Hormonausschüttungen durch das kompetitive Videospielen die Wahrnehmungsfähigkeit beeinflussen könnte. Wie dargestellt, werden im E-Sport primär kognitive Fähigkeiten benötigt (vgl. Kap. 2.4), was die Wahrscheinlichkeit erhöht, dass mentale Ermüdung schneller als muskuläre Ermüdung eintritt. Dementsprechend könnten die Probanden eher ihre psychophysische Gesamterschöpfung bewertet haben als ausschließlich die körperliche Anstrengung. Diese Überlegung wird gestützt durch die Analyse der WKV-Dimensionen „Aktiviertheit“, „Trainiertheit“ und „Beweglichkeit“, die sich analog zur Borg-Skala verhielten (Studie II). Die Adjektive für die Dimensionen „Trainiertheit“ und „Beweglichkeit“ sind eindeutig körperlichen Aspekten zuzuordnen (bspw. kräftig, fit, gelenkig, steif). Demgegenüber enthält die Dimension „Aktiviertheit“ zu bewertende Begriffe wie, „energielos“, „ausgelaugt“ oder „platt“, die auch psychisch interpretiert werden können. Somit könnten die genutzten Instrumente nicht trennscharf genug sein, um rein körperliche Anstrengung valide zu erfassen.

Demzufolge ist der Einsatz verschiedener Messinstrumente zur Trainingssteuerung und zum Belastungsmonitoring im E-Sport zu empfehlen. Subjektive Skalen stellen dabei eine kostengünstige und praktikable Methode dar, um individuelle Beanspruchungseinschätzungen regelmäßig zu erfassen. Wie die vorliegenden Ergebnisse jedoch zeigen, sind diese Verfahren nicht ausreichend sensitiv, um eine Akkumulation neurophysiologischer Ermüdung valide abzubilden. Daraus ergibt sich die Gefahr, dass die tatsächliche körperliche Beanspruchung unterschätzt wird. Um eine differenzierte Diagnostik zu ermöglichen, sollten psychische und physische Beanspruchungsparameter mit jeweils spezifischen Instrumenten erfasst werden. Ergänzend empfiehlt sich der Einsatz objektiver Messverfahren, um die subjektiven Angaben zu überprüfen und individuelle Beanspruchungsmuster umfassender abzubilden. Solche Verfahren können sowohl zur Validierung von Intero- und Exterozeption sowie als rückgekoppeltes Feedbacksystem im Rahmen der Trainingssteuerung dienen.

Resümierend zeigen die Ergebnisse dieser Arbeit, dass kompetitives Videospielen bereits bei einer mehrstündigen Videospieleinheit zu einer signifikanten Zunahme muskulärer Ermüdung sowie der subjektiv wahrgenommenen körperlichen Beanspruchung führt. Die eingesetzte passive Erholungspause führte zu einer signifikanten Reduktion der subjektiv wahrgenommenen körperlichen Beanspruchung, erwies sich jedoch als nicht ausreichend, um die neurophysiologische Beanspruchung wirksam zu kompensieren. Bei unzureichender Regeneration und fehlenden kompensatorischen Ressourcen besteht die Gefahr einer kumulativen Überbeanspruchung, die das Risiko für die Entstehung von MSE bei E-Sportler*innen langfristig deutlich erhöhen kann.

7.2 Methodendiskussion

Die vorliegende Dissertation untersuchte in drei aufeinander aufbauenden Fragestellungen die körperliche Belastung und Beanspruchung im E-Sport sowie deren potenzielle Assoziation mit muskuloskelettalen Erkrankungen. Die jeweiligen methodischen Stärken und Limitationen der Einzelstudien wurden bereits in den zugehörigen Publikationen reflektiert. Im Folgenden erfolgt daher eine zusammenfassende und kritische Bewertung der angewandten Methoden im Hinblick auf die übergeordneten Fragestellungen.

Zur Erörterung der Hauptfragestellung wurde zunächst eine systematische Literaturanalyse erstellt, da zum Zeitpunkt der Durchführung keine Übersichtsarbeit zu MSE bei Videospielenden vorlag. Die Übersicht lieferte wertvolle Hinweise auf mögliche Zusammenhänge zwischen Videospielzeit und Beschwerderisiko. Allerdings basierten die eingeschlossenen Studien überwiegend auf Querschnittsdesigns, sodass keine Aussagen zur Kausalität möglich sind. Hinzu kam eine erhebliche Heterogenität der untersuchten Populationen, was auf das Fehlen einer einheitlichen Definition von E-Sportler*in zurückzuführen ist (Bubna et al., 2023). Diese Uneinheitlichkeit erschwert den gesamtwissenschaftlichen Diskurs und beschränkt die Evidenzlage. Trotz dieser Einschränkungen stellt die Übersichtsarbeit einen wichtigen Ausgangspunkt für weitere Untersuchungen dar und leistet einen grundlegenden Beitrag zur systematischen Aufarbeitung der Thematik.

Um die in der Literatur identifizierten Zusammenhänge empirisch zu überprüfen, wurde eine quasi-experimentelle Untersuchung (Studie II & III) durchgeführt. Diese zeichneten sich durch eine kontrollierte Untersuchungsumgebung sowie ein feldnahes Design aus. Zusätzlich war die Definition der E-Sportler*innen klar operationalisiert. Methodische Limitationen ergeben sich jedoch durch das Fehlen einer Kontrollgruppe und die nicht randomisierte Zuweisung der Bedingungen, was die interne Validität einschränkt (Schweizer et al., 2016). Zur teilweisen Kontrolle dieser Effekte wurden Messwiederholungen eingesetzt, was eine differenziertere Analyse intraindividueller Veränderungen ermöglichte. Eine weitere Limitation ergibt sich aus der praktischen Durchführung der kompetitiven Spielsituationen: Um an Ranglistenspielen teilnehmen zu können, mussten die Teilnehmenden variable Wartezeiten in sogenannten „*Matchmaking-Queues*“ (Warteschlangen) durchlaufen. Diese liegen zwischen wenigen Sekunden bis zu zehn Minuten, abhängig vom individuellen Spielrang. Dadurch ergaben sich unkontrollierte Pausen, die zu interindividuell variierenden Gesamtspielzeiten führten. Zusätzlich kann es innerhalb der Videospiele zu kurzen Unterbrechungen kommen, wenn beispielsweise der eigene Avatar gestorben ist und E-Sportler*innen warten müssen, bis dieser wieder in das Spiel eintritt. Da sich diese Unterschiede unmittelbar auf die Beanspruchung auswirken können, sollten zukünftige Studien die tatsächlichen Wartezeiten systematisch erfassen und als Kovariate in statistische Modelle einbeziehen. Darüber hinaus wurden unterschiedliche Videospielgenres und E-Sport-Titel in die Untersuchung miteinbezogen. Diese könnten potenziell verschiedene Belastungen an die E-Sportler*innen stellen, vergleichbar mit unterschiedlichen traditionellen Sportarten. Um diesen Unterschied so gering wie möglich zu halten, wurden nur computerbasierte Videospiele mit Maus- und Tastatursteuerung miteinbezogen.

Zur Erfassung der körperlichen Beanspruchung wurden in den Studien II und III sowohl subjektive als auch objektive Messinstrumente eingesetzt, wodurch ein differenzierteres Verständnis der Belastungssituation im E-Sport möglich wurde. Die Borg- und WKV-Skala gelten als etablierte und validierte Verfahren in sport- und arbeitsbezogenen Kontexten (vgl. Kap. 2.2.2). Ihre Anwendung im E-Sport-Kontext ist methodisch sinnvoll, da sie eine ökonomische und praktikable Möglichkeit bieten, individuelle Beanspruchungseinschätzungen zu erfassen. Jedoch bleibt fragwürdig, ob diese eine ausreichende Trennschärfe zwischen körperlichen und mentalen Konstrukten aufweisen. Zukünftigen Untersuchungen ist daher die separate Erhebung sensitiver psychischer und physischer Beanspruchungsparameter zu empfehlen.

Zur objektiven Erfassung muskulärer Ermüdung wurde das Oberflächen-EMG genutzt, wobei die Medianfrequenz und die elektrische Aktivität als Indikator für Ermüdung dienten. Diese Methoden sind in der Sport- und Arbeitswissenschaft weit verbreitet und grundsätzlich geeignet, akute Ermüdungsvorgänge sichtbar zu machen (vgl. Kap. 2.2.2). Dennoch unterliegt die EMG-Messung gewissen Einschränkungen hinsichtlich der Standardisierung und liefert nur indirekte Hinweise auf funktionelle Einschränkungen. Zusätzlich wurden lediglich vier Messzeitpunkte ausgewertet, anstatt die ganze Messperiode, was auf die nicht systematisch erfassten Pausen zwischen den Ranglistenspielen zurückzuführen ist. Zudem wären Regressionsanalysen im Sinne der „*Joint Analysis of Spectrum and Amplitude*“ (JASA) eine sinnvolle Ergänzung gewesen, um detailliertere Einblicke in die Verläufe der neuromuskulären Ermüdung zu erhalten, was jedoch aufgrund der hohen Varianz der Ergebnisse nicht möglich war (Luttmann et al., 2000). Darüber hinaus wurden lediglich zwei Muskelgruppen erfasst (Musculus trapezius pars descendens und Musculus extensor digitorum), was zwar methodisch fokussiert, aber hinsichtlich der Gesamtbeanspruchung im E-Sport nur einen Teilaspekt abbildet. Eine Erweiterung auf zusätzliche Muskelgruppen, beispielsweise des Musculus erector spinae oder die abdominellen Muskeln, wäre für weiterführende Analysen sinnvoll, da gerade diese bei langanhaltender, monotoner sedentärer Aktivität beansprucht werden (Amiri et al., 2025). Des Weiteren beschränkten sich die Untersuchungen auf rein körperliche Anforderungen. Um ein ganzheitliches Belastungs- und Beanspruchungskonzept des E-Sports zu entwickeln, sollten weitere psychometrische Erhebungen oder objektive Verfahren zur Messung mentaler Ermüdung, wie Lidschlussanalysen, Papillometrie oder elektroenzephalographische Verfahren, in Zukunft stärker berücksichtigt werden.

Die ergänzende Erhebung kinematischer Parameter blieb in den vorliegenden Studien ohne signifikante Veränderungen. Dies kann sowohl auf eine tatsächliche Konstanz der Bewegungsmuster als auch auf eine begrenzte Sensitivität der erfassten Bewegungsparameter hinweisen. Die Validität kinematischer Marker als Belastungsindikatoren im E-Sport bedarf daher weiterer konzeptioneller und methodischer Klärung.

8. Implikationen für Forschung und Praxis

Vor dem Hintergrund der in dieser Dissertation gewonnenen Erkenntnisse lassen sich konkrete Implikationen sowohl für die zukünftige Forschung als auch für die praktische Anwendung im E-Sport ableiten.

Studie I verdeutlicht den erheblichen Mangel an Interventions- und Expositionsstudien im Bereich MSE im E-Sport. Dieses Defizit betrifft ebenfalls psychologische und physiologische Forschungsfelder (Dupuy et al., 2024; Leis & Lautenbach, 2020). Um belastbare Aussagen über Wirkmechanismen treffen zu können, sind kontrollierte Studiendesigns erforderlich, die reale Belastungssituationen im E-Sport angemessen abbilden. Ein zentrales Problem besteht darin, dass viele bisherige Studien deutlich zu kurze Videospielzeiten ansetzen (vgl. Studie I), die weder den Trainings- noch den Wettkampfbedingungen von E-Sportler*innen entsprechen (DiFrancisco-Donoghue et al., 2019; Soffner et al., 2023). Zukünftige Interventionsstudien sollten deshalb realitätsnahe Expositionszeiten von mindestens 60-120 Minuten oder länger einplanen, um einen Praxistransfer der Ergebnisse zu gewährleisten.

Darüber hinaus besteht in der Forschung ein Bedarf an klaren, einheitlichen Definitionen der Zielgruppen. Derzeitige Studien unterscheiden häufig nicht zwischen Videospielenden, ambitionierten E-Sportler*innen und Profis, was die Vergleichbarkeit der Ergebnisse erschwert (Bubna et al., 2023). Dementsprechend sollte eine einheitliche Terminologie angestrebt werden. Ein praktikabler Ansatz wurde in Studie II & III durch die Verwendung der spielinternen Ranglisten als Kriterium eingeführt. Um jedoch eine weitergehende Unterscheidung zwischen Leistungsniveaus zu ermöglichen, sollte zukünftig zusätzlich erfasst werden, ob E-Sportler*innen auf professioneller Ebene (z. B. Einkommenssicherung über E-Sport, Teilnahme an Top-Ligen) aktiv sind. Eine Orientierung an der sportsoziologischen Definition professioneller Sportausübung ist hier naheliegend (Coakley, 2016), wenngleich die finanzielle Tragfähigkeit in vielen E-Sport-Disziplinen eingeschränkt bleibt und stark abhängig von externen Sponsoren ist (Freitas, 2023).

Ein weiterer methodischer Aspekt betrifft die Auswahl geeigneter Kontrolltätigkeiten in Studien mit experimentellen Designs. Da kompetitives Videospielen durch interaktive, dynamische und kognitiv anspruchsvolle Reize charakterisiert ist, gestaltet sich die Wahl einer adäquaten Kontrollbedingung herausfordernd. Denkbar wäre ein Vergleich mit nicht-kompetitiven Spielmodi oder wiederholbaren Standardsituationen innerhalb der Videospiele mit vergleichbarer Dauer und Belastung.

Des Weiteren sollten zukünftige Studien unterschiedliche Pausenformate untersuchen. Studien weisen bereits darauf hin, dass leichte körperliche Aktivität zwischen sitzenden Tätigkeiten kognitive Parameter positiv beeinflussen kann (Chandrasekaran et al., 2021; Chrismas et al., 2019). Ebenfalls mit E-Sportler*innen konnte gezeigt werden, dass eine Gehpause zwischen Videospieleinheiten eine positive Auswirkung auf exekutive Funktionen haben kann (DiFrancisco-Donoghue et al., 2021). Dementsprechend sollten zukünftige Studien unterschiedliche Arten der Pausengestaltung (aktive und passive Maßnahmen) sowie verschiedene Pausenlängen untersuchen. Insbesondere körperlich aktive Pausen sollten nach den anerkannten Belastungsnormativen Frequenz (F), Intensität (I), Typ (T) und Dauer oder Zeit (Z) (FITZ-Prinzipien) konzipiert und beschrieben werden (Donath & Faude, 2019). Somit wird eine hohe Vergleichbarkeit der Studien und eine möglichst detaillierte Beschreibung der Belastungsdosierung gewährleistet. Folglich lässt sich jedes einzelne Belastungsmerkmal als Variable und Untersuchungsgegenstand in zukünftigen Studien heranziehen. Manci et al. (2024) haben diesbezüglich bereits erste theoretische Überlegungen im Kontext E-Sport dargelegt. Aber nicht nur die Pausengestaltung, sondern insbesondere Trainingsinterventionen sollten sich nach den FITZ-Prinzipien richten. Dadurch erhöht sich nicht nur die Transparenz und

Replizierbarkeit, sondern es wird auch die Grundlage für metaanalytische Betrachtungen mit hoher Homogenität geschaffen.

Wie Studie III darstellen konnte, stellt die Analyse der Medianfrequenz zur Feststellung der muskulären Ermüdung im E-Sport ein geeignetes Verfahren dar. Die Betrachtung der elektrischen Aktivität wies jedoch divergente Ergebnisse auf, insbesondere wenn beide Parameter (Medianfrequenz und Amplitudenverlauf) gemeinsam betrachtet wurden. Nach Luttmann et al. (2000) liegt muskuläre Ermüdung vor, wenn die elektrische Aktivierung steigt und gleichzeitig das Frequenzspektrum abnimmt. Dieser Zusammenhang gilt jedoch primär für isometrische oder hochdynamische Muskelaktivitäten. Da das kompetitive Videospielen durch submaximale, repetitive Beanspruchungen geprägt ist, sollten zukünftig Analyseverfahren eingesetzt werden, die speziell für niedrigschwellige Muskelaktivitäten sensitiv sind. Zudem sollten Variablen wie die Warteschlangenzeit, das Leistungsniveau und der Trainingsumfang als Kovariaten in statistische Modelle integriert werden, um die Aussagekraft zukünftiger Studien zu erhöhen.

Neben den dargestellten Implikationen für zukünftige Forschungsvorhaben ergeben sich aus den Ergebnissen dieser Dissertation auch konkrete Handlungsempfehlungen für die Praxis im E-Sport. Insbesondere die identifizierten Belastungsfaktoren sowie die nachgewiesene Diskrepanz zwischen objektiver und subjektiver Beanspruchung unterstreichen die Notwendigkeit, Trainingsstrukturen, Regenerationsstrategien und gesundheitspräventive Maßnahmen gezielt zu optimieren. Ein regelmäßiges Monitoring der physischen und psychischen Beanspruchung sollte in Trainingsalltag und Turniervorbereitung integriert werden. Als praktikable Instrumente haben sich die modifizierte Borg-Skala und die WKV-Skala erwiesen (vgl. Studie II). Jedoch sollte hier differenziert die physische und psychische Beanspruchung erfragt werden. Ergänzt werden können diese durch visuelle Analogskalen oder numerische Ratingskalen zur Erfassung von Fatigue und Schmerz (Hilfiker, 2008; Lee et al., 1991). Darüber hinaus sollten standardisierte Fragebögen eingesetzt werden, um biopsychosoziale Belastungszustände frühzeitig zu erkennen und um geeignete Maßnahmen einzuleiten. Zur Objektivierung der individuellen Beanspruchung kann die Herzratenvariabilität (HRV) genutzt werden (Mosley & Laborde, 2024). Diese spiegelt die parasympathische Aktivität des Nervensystems wider und lässt unter anderem Rückschlüsse auf den Erholungszustand einer Person zu (ebd.). Die brustgurtbasierte

HRV-Messung liefert dabei valide Ergebnisse und kann bereits mit kostengünstigen Herzfrequenzsensoren erhoben und analysiert werden (Laborde et al., 2017).

Ein weiterer wichtiger Punkt ist die Periodisierung des Trainingsalltags und damit verbunden das aktive Planen von Belastungs- und Erholungsphasen. Wie in der vorliegenden Arbeit gezeigt werden konnte, herrscht im E-Sport häufig ein Belastungs-Beanspruchungsproblem (vgl. Kap. 2.4). Dabei sind die Belastungsphasen durch sedentäres Verhalten, partielle körperliche Überforderung und mentale Überlastung gekennzeichnet. Dementsprechend sollten die Erholungsphasen eine körperliche Aktivierung und mentale Entspannung fördern. Dies wird unterstrichen durch die Ergebnisse der Studie III, in welcher eine passive Pause keinen Einfluss auf die muskuläre Ermüdung hatte. Körperlich aktive Pausen können beispielsweise aus kurzen Gehpausen, dynamischen Dehn- oder Kräftigungsübungen bestehen. Ein essenzielles Ziel dabei sollte sein, möglichst viele Muskelgruppen zu aktivieren, insbesondere die Beinmuskulatur, um den Blutfluss und damit die Nähr- und Sauerstoffversorgung der unterschiedlichen Gewebestrukturen und Organe zu erhöhen (Restaino et al., 2015). Auf der anderen Seite können aktive Entspannungsverfahren bei mentaler Überforderung oder zur Stressregulation helfen (Zisopoulou & Varvogli, 2023). Unter anderem sind dafür Atemübungen, Autogenes Training oder die progressive Muskelrelaxation geeignet (ebd.). Insbesondere bei Turnierformaten sollte auf solche psychophysiologischen Regulationsmechanismen zurückgegriffen werden, um E-Sportler*innen eine schnelle und einfache Möglichkeit zu bieten Stress abzubauen. Neben der aktiven Pausenplanung, welche täglich Anwendung finden sollte, wird als Ausgleich ein gezieltes Krafttraining mehrmals wöchentlich empfohlen. Die WHO empfiehlt mindestens zwei Krafteinheiten pro Woche zur Steigerung der Gesundheit, für leistungsbezogene Effekte sind diese Empfehlungen zu überschreiten (World Health Organization, 2020). Im Fokus stehen dabei besonders beanspruchte Muskelgruppen wie Handgelenksextensoren, Nackenmuskulatur und Rumpfstabilisatoren. FITZ-konzipierte Trainingspläne bieten hierfür eine geeignete methodische Grundlage.

Neben dem dargestellten Erkenntnisgewinn war es ein zentrales Ziel dieser Dissertation, ein adaptives Belastungs-Beanspruchungsmodell für den E-Sport zu entwickeln, das sowohl für die empirische Forschung als auch für praktische Anwendungsfelder von Relevanz ist. Die theoretischen Vorüberlegungen zu diesem

Modell wurden in Kapitel 2 dargestellt und durch die empirischen Ergebnisse und die Diskussion der drei vorgestellten Studien untermauert. Als konzeptionelle Grundlage dient das erweiterte Belastungs-Beanspruchungsmodell wie es im Arbeitsschutz etabliert und in der Normenreihe DIN EN ISO 10075 verankert ist (Deutsches Institut für Normung, 2018). Abbildung 5 zeigt das adaptierte Modell[1], welches beschreibt, dass biopsychosoziale Belastungen zu individuellen, unmittelbaren Beanspruchungen führen und illustriert deren potenzielle Folgen. Sowohl die Beanspruchungen als auch die Beanspruchungsfolgen werden durch internale und externale Ressourcen moderiert. In zyklischen Rückkopplungsprozessen können die Beanspruchungsfolgen die Belastungsfaktoren oder Ressourcenzustände beeinflussen.

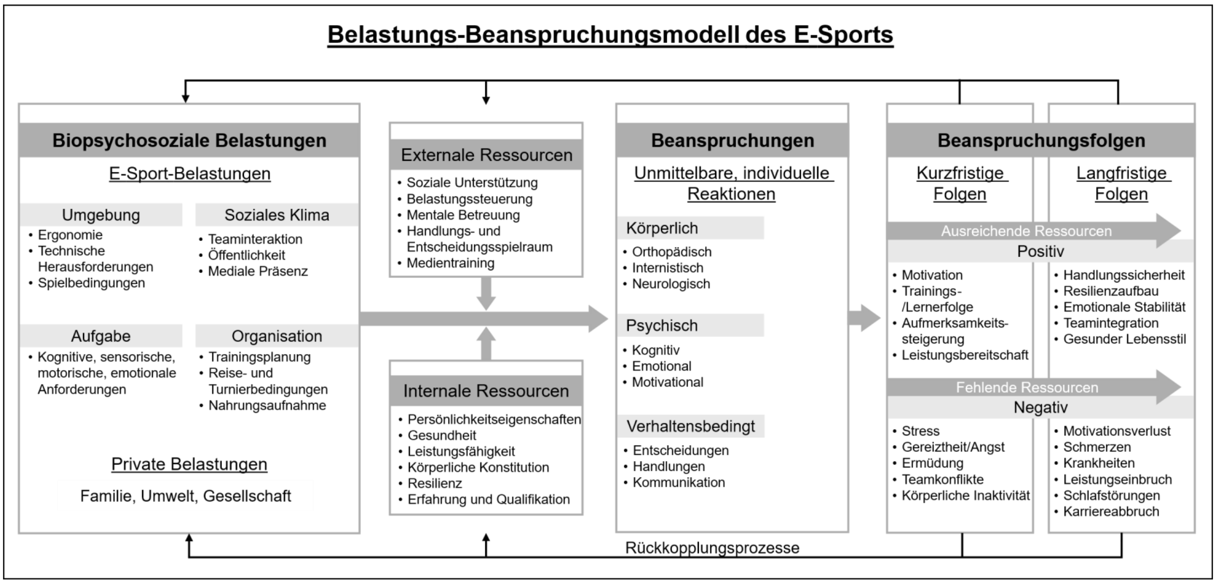

Abbildung 5: Belastungs-Beanspruchungsmodell des E-Sports, angelehnt an das erweiterte Belastungs-Beanspruchungsmodell nach DIN (2018) (eigene Darstellung).

Im Zentrum der biopsychosozialen Belastungen stehen die E-Sport-spezifischen Belastungen, die in vier Hauptkategorien differenziert werden: Umgebungsbedingungen, soziales Klima, Aufgabenanforderungen und organisationale Aspekte (Deutsches Institut für Normung, 2018). Zusätzlich werden private Belastungen berücksichtigt, wie die familiäre Unterstützung, Umweltfaktoren oder gesellschaftlicher Rückhalt. Zu den Umgebungsfaktoren zählen ergonomische Parameter (Licht, Lärm, Raumklima), die korrekte Einstellung der Spielausstattung (Sitzhaltung, Bildschirmposition), aber auch technische Aspekte wie Hardware- und

[1] Eine größere Darstellung des Modells befindet sich im Anhang.

Softwarestabilität sowie Netzwerkqualität. Eine besondere Belastung stellen Spielveränderungen durch sogenannte Patches oder Updates dar, die gewohnte Spielbedingungen teilweise oder grundlegend verändern können (Kica et al., 2016). Diese Eingriffe lassen sich mit regeltechnischen Anpassungen im traditionellen Sport vergleichen, wie etwa Änderungen an Spielregeln oder Geräteparametern, die die sportliche Leistung erheblich beeinflussen können. Studien zeigen, dass solche Patches die Spielbalance beeinflussen und damit messbare Effekte auf spielrelevante Statistiken sowie die Leistungsverteilung innerhalb der Spielgemeinschaft haben (He et al., 2021; Kica et al., 2016). Das soziale Klima umfasst sowohl teaminterne Faktoren (Kommunikation, Konflikte, Kohäsion) als auch externen sozialen Druck durch Turnierpublikum, Community-Erwartungen oder mediale Präsenz (Leis et al., 2024; Sharpe et al., 2024). Im Bereich der Aufgabenanforderungen steht die Kombination aus kognitiver Entscheidungsdichte, Multitasking, sensorischer Informationsverarbeitung und feinmotorischen Ausführungen im Vordergrund (Campbell et al., 2018; Nagorsky & Wiemeyer, 2020). Organisationale Belastungen ergeben sich unter anderem aus unzureichender Regenerationsplanung (Manci et al., 2024), Reiseverpflichtungen sowie Termin- und Zeitkonflikte (Leis et al., 2024). Die beschriebenen Belastungen führen zu unmittelbaren Beanspruchungsreaktionen. Das Ausmaß und die Qualität dieser Reaktionen werden durch internale und externale Ressourcen moderiert (Deutsches Institut für Normung, 2018). Zu den externalen Ressourcen zählen das soziale Umfeld oder das Team (Leis et al., 2024), die Belastungssteuerung durch Trainer*innen, stabile arbeitsbezogene Rahmenbedingungen wie das Anstellungsverhältnis (Sonnentag & Frese, 2012) sowie die Partizipation an teaminternen Entscheidungsprozessen, die das Autonomieerleben und die Kontrollüberzeugung fördern können (Deci & Ryan, 2000). Internale Ressourcen beziehen sich auf individuelle Merkmale wie Persönlichkeitseigenschaften (z. B. Gewissenhaftigkeit, Kontrollüberzeugung), den aktuellen Gesundheits- und Trainingszustand, die körperliche Konstitution (z. B. Ausdauer, Muskelmasse, Mobilität) (Deutsches Institut für Normung, 2018) sowie psychologische Schutzfaktoren wie Erfahrung, Selbstwirksamkeit und Resilienz (Judge & Bono, 2001). Die daraus resultierenden Beanspruchungsreaktionen lassen sich auf drei Ebenen beschreiben:

- Körperlich: Muskelaktivierung, Herzfrequenzanstieg, neuronale Aktivität, Blutdrucksteigerung, Regulation der Atemfrequenz
- Psychisch: emotionale Regulation, kognitive Leistungsfähigkeit, Motivation
- Verhaltensbezogen: Handlungsqualität, Entscheidungsverhalten, Kommunikation

Die genannten Punkte stellen exemplarische Beanspruchungsreaktionen dar und erheben keinen Anspruch auf Vollständigkeit. Diese Reaktionen haben kurz- und langfristige Beanspruchungsfolgen. Bei unzureichenden Ressourcen überwiegen tendenziell negative Beanspruchungsfolgen, wie etwa kurzfristige Ermüdung, Stress oder Leistungseinbußen (Demerouti et al., 2001). Langfristig kann dies zu Motivationsverlust, gesundheitlichen Beschwerden oder sogar in einem frühzeitigen Karriereende münden (ebd.). Positive Beanspruchungsfolgen treten dagegen vor allem dann auf, wenn ausreichende Ressourcen zur Bewältigung der Belastung vorhanden sind. Kurzfristig können sich diese in Motivationssteigerung (Deci & Ryan, 2000), erhöhter Leistungsbereitschaft oder Trainingserfolgen äußern (DeWeese et al., 2015). Langfristig kann dies zur Handlungssicherheit, emotionalen Stabilität und Etablierung gesundheitsförderlicher Verhaltensweisen beitragen (vgl. Kap. 2.3). In Form einer Rückkopplungsschleife wirken die erlebten Beanspruchungsfolgen wiederum auf die individuelle Ressourcenbasis und die Belastungssituation zurück (Demerouti et al., 2001). Dies kann sich beispielsweise in Form von Erschöpfung und verringerter Belastbarkeit äußern, aber auch durch positive Adaptionen wie Trainingseffekte und eine gesteigerte Stressresistenz. Dadurch verändert sich auch das Beanspruchungserleben in zukünftigen Belastungssituationen.

Das vorliegende Modell stellt somit ein theoretisch fundiertes und empirisch gestütztes Rahmenkonzept dar, das zur systematischen Analyse von Belastungsfaktoren und Beanspruchungsprozessen im E-Sport beitragen kann.

9. Fazit und Ausblick

Die vorliegende Dissertation verfolgte das Ziel, die muskuloskelettale Belastung und Beanspruchung im E-Sport systematisch zu untersuchen und deren potenzielle gesundheitliche Folgen zu analysieren. Auf Grundlage einer dreiteiligen empirischen Forschungsstrategie, bestehend aus einer systematischen Übersichtsarbeit (Studie I) sowie einer quasi-experimentellen Untersuchung (Studie II & III) konnten zentrale Einflussfaktoren, Belastungsmechanismen und Beanspruchungsreaktionen identifiziert werden.

Die Ergebnisse der Studien II und III zeigen, dass bereits eine einmalige, mehrstündige Videospielexposition zu einer signifikanten Zunahme muskulärer Ermüdung sowie einer subjektiv wahrgenommenen Steigerung der Beanspruchung führt, während die kinematische Belastung über die Spielzeit hinweg konstant bleibt. Eine zehnminütige passive Pause reichte in diesem Kontext nicht aus, um die objektiv messbare muskuläre Ermüdung zu kompensieren. Darüber hinaus wurde eine teils deutliche Diskrepanz zwischen der subjektiv wahrgenommenen körperlichen Anstrengung und der objektiv erfassten Beanspruchung festgestellt. Diese Erkenntnisse unterstreichen die Notwendigkeit, in zukünftigen Studien sowohl die psychophysische Beanspruchung differenzierter zu erfassen als auch verschiedene Regenerationsstrategien zu evaluieren.

Gleichzeitig zeigt die systematische Übersichtsarbeit (Studie I), dass der aktuelle Forschungsstand im Wesentlichen auf Querschnittsanalysen basiert. Diese Designs erlauben zwar erste Einblicke in potenzielle Zusammenhänge zwischen Videospielverhalten und Muskel-Skelett-Erkrankungen, lassen jedoch keine kausalen Aussagen zu. Auch das quasi-experimentelle Studiendesign dieser Dissertation erlaubt lediglich die Ableitung erster Indizien. Zukünftige Forschungsarbeiten sollten kontrollierte Studiendesigns mit realitätsnahen Belastungsszenarien und differenzierten Interventionskomponenten einsetzen, um kausale Wirkmechanismen zu identifizieren.

Neben der empirischen Untersuchung wurde ein theoretisch fundiertes, adaptives Belastungs-Beanspruchungsmodell für den E-Sport entwickelt, das auf dem arbeitspsychologischen Rahmenkonzept gemäß DIN EN ISO 10075 basiert (Deutsches Institut für Normung, 2018). Dieses Modell berücksichtigt spezifische

Belastungsquellen im E-Sport sowie die Bedeutung individueller Ressourcen für die Verarbeitung von Beanspruchung. Es verdeutlicht die dynamische Wechselwirkung zwischen Belastungen, Beanspruchungsreaktionen und deren kurz- und langfristigen Folgen. Da dieses Modell bislang vorwiegend auf theoretischen Annahmen und ersten empirischen Befunden basiert, sollte es zukünftig durch multizentrische, multimodale Studien überprüft und weiterentwickelt werden.

Zusammenfassend lässt sich feststellen, dass der E-Sport nicht nur kognitive, sondern auch körperliche Anforderungen stellt, die mit spezifischen Belastungen und Beanspruchungsreaktionen einhergehen. Die Ergebnisse unterstreichen die Relevanz einer sportwissenschaftlich fundierten Betrachtung des E-Sports sowohl im Sinne einer verbesserten Gesundheitsprävention als auch hinsichtlich einer evidenzbasierten Trainingssteuerung. Das entwickelte Modell liefert sowohl Ansatzpunkte für weitere Forschung als auch praktische Orientierungshilfen für Trainer*innen, E-Sport-Organisationen und Gesundheitsexpert*innen.

VI. Literaturverzeichnis

Aicale, R., Tarantino, D. & Maffulli, N. (2018). Overuse injuries in sport: a comprehensive overview. *Journal of orthopaedic surgery and research*, *13*(1), 309. https://doi.org/10.1186/s13018-018-1017-5

AlOmar, R. S., AlShamlan, N. A., Alawashiz, S., Badawood, Y., Ghwoidi, B. A. & Abugad, H. (2021). Musculoskeletal symptoms and their associated risk factors among Saudi office workers: a cross-sectional study. *BMC musculoskeletal disorders*, *22*(1), 763. https://doi.org/10.1186/s12891-021-04652-4

Amiri, B., Behm, D. G. & Zemková, E. (2025). On the Role of Core Exercises in Alleviating Muscular Fatigue Induced by Prolonged Sitting: A Scoping Review. *Sports medicine - open*, *11*(1), 18. https://doi.org/10.1186/s40798-025-00816-x

Arvidsson, I., Axmon, A. & Skerfving, S. (2008). Follow-up study of musculoskeletal disorders 20 months after the introduction of a mouse-based computer system. *Scandinavian journal of work, environment & health*, *34*(5), 374–380. https://doi.org/10.5271/sjweh.1277

Badura, B., Ducki, A., Baumgardt, J., Meyer, M. & Schröder, H. (Hrsg.). (2024). *Fehlzeiten-Report: Bd. 2024*. *Fehlzeiten-Report 2024: Bindung und Gesundheit - Fachkräfte Gewinnen und Halten*. Springer. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=31755489

Baradaran Mahdavi, S., Riahi, R., Vahdatpour, B. & Kelishadi, R. (2021). Association between sedentary behavior and low back pain; A systematic review and meta-analysis. *Health promotion perspectives*, *11*(4), 393–410. https://doi.org/10.34172/hpp.2021.50

Barbe, M. F., Gallagher, S., Massicotte, V. S., Tytell, M., Popoff, S. N. & Barr-Gillespie, A. E. (2013). The interaction of force and repetition on musculoskeletal and neural tissue responses and sensorimotor behavior in a rat model of work-related musculoskeletal disorders. *BMC musculoskeletal disorders*, *14*, 303. https://doi.org/10.1186/1471-2474-14-303

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise*, *14*(5), 377–381.

Borg, G. (1998). *Borg's Perceived exertion and pain scales*. Human Kinetics.

Boyas, S. & Guével, A. (2011). Neuromuscular fatigue in healthy muscle: underlying factors and adaptation mechanisms. *Annals of physical and rehabilitation medicine*, *54*(2), 88–108. https://doi.org/10.1016/j.rehab.2011.01.001

British Esports Association. (2021). *Tournament formats in esports*. https://britishesports.org/the-hub/advice/tournament-formats-in-esports/?utm_source=chatgpt.com

Bubna, K., Trotter, M. G., Polman, R. & Poulus, D. R. (2023). Terminology matters: defining the esports athlete. *Frontiers in sports and active living*, *5*, 1232028. https://doi.org/10.3389/fspor.2023.1232028

Bullinger, H.-J. (1994). Arbeitsphysiologie. In H.-J. Bullinger & H.-J. Bullinger (Hrsg.), *Technologiemanagement - Wettbewerbsfähige Technologieentwicklung und Arbeitsgestaltung. Ergonomie* (S. 29–75). Vieweg+Teubner Verlag. https://doi.org/10.1007/978-3-663-12094-0_3

Burke, A. & Peper, E. (2002). Cumulative trauma disorder risk for children using computer products: Results of a pilot investigation with a student convenience sample. *Public Health Reports*, *117*(4), 350–357. https://doi.org/10.1016/s0033-3549(04)50171-1

Callegari, B., Resende, M. M. de & Da Silva Filho, M. (2018). Hand rest and wrist support are effective in preventing fatigue during prolonged typing. *Journal of hand therapy : official journal of the American Society of Hand Therapists*, *31*(1), 42–51. https://doi.org/10.1016/j.jht.2016.11.008

Campbell, M. J., Toth, A. J., Moran, A. P., Kowal, M. & Exton, C. (2018). eSports: A new window on neurocognitive expertise? *Progress in brain research*, *240*, 161–174. https://doi.org/10.1016/bs.pbr.2018.09.006

Chandrasekaran, B., Pesola, A. J., Rao, C. R. & Arumugam, A. (2021). Does breaking up prolonged sitting improve cognitive functions in sedentary adults? A mapping review and hypothesis formulation on the potential physiological mechanisms. *BMC musculoskeletal disorders*, *22*(1), 274. https://doi.org/10.1186/s12891-021-04136-5

Chrismas, B. C. R., Taylor, L., Cherif, A., Sayegh, S. & Bailey, D. P. (2019). Breaking up prolonged sitting with moderate-intensity walking improves attention and executive function in Qatari females. *PloS one*, *14*(7), e0219565. https://doi.org/10.1371/journal.pone.0219565

Coakley, J. (2016). *Sports in Society:: Issues and Controversies* (12. Aufl.). McGraw-Hill Education.

Coughlin, S. S. (1990). Recall bias in epidemiologic studies. *Journal of Clinical Epidemiology*(43), Artikel 1.

David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine (Oxford, England)*, *55*(3), 190–199. https://doi.org/10.1093/occmed/kqi082

De Luca, C. J. (1984). Myoelectrical manifestations of localized muscular fatigue in humans. *Critical reviews in biomedical engineering*, *11*(4), 251–279.

Deci, E. L. & Ryan, R. M. (2000). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

Demerouti, E., Bakker, A. B., Nachreiner, F. & Schaufeli, W. B. (2001). The job demands-resources model of burnout. *Journal of Applied Psychology*, *86*(3), 499–512. https://doi.org/10.1037/0021-9010.86.3.499

Deutsches Institut für Normung (2018). *Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung – Teil 1: Allgemeine Aspekte sowie Konzepte und Begriffe* (DIN EN ISO 10075-1). DIN Media GmbH.

DeWeese, B. H., Hornsby, G., Stone, M. & Stone, M. H. (2015). The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *Journal of sport and health science*, *4*(4), 308–317. https://doi.org/10.1016/j.jshs.2015.07.003

DiFrancisco-Donoghue, J., Balentine, J., Schmidt, G. & Zwibel, H. (2019). Managing the health of the eSport athlete: an integrated health management model. *BMJ Open Sport & Exercise Medicine*, *5*(1), e000467. https://doi.org/10.1136/bmjsem-2018-000467

DiFrancisco-Donoghue, J., Jenny, S. E., Douris, P. C., Ahmad, S., Yuen, K., Hassan, T., Gan, H., Abraham, K. & Sousa, A. (2021). Breaking up prolonged sitting with a 6 min walk improves executive function in women and men esports players: a randomised trial. *BMJ Open Sport & Exercise Medicine*, *7*(3), e001118. https://doi.org/10.1136/bmjsem-2021-001118

DiFrancisco-Donoghue, J., Werner, W. G., Douris, P. C. & Zwibel, H. (2020). Esports players, got muscle? Competitive video game players' physical activity, body fat, bone mineral content, and muscle mass in comparison to matched controls. *Journal of sport and health science.* Vorab-Onlinepublikation. https://doi.org/10.1016/j.jshs.2020.07.006

Ding, Y., Cao, Y., Duffy, V. G. & Zhang, X. (2020). It is Time to Have Rest: How do Break Types Affect Muscular Activity and Perceived Discomfort During Prolonged Sitting Work. *Safety and health at work*, *11*(2), 207–214. https://doi.org/10.1016/j.shaw.2020.03.008

Donath, L. & Faude, O. (2019). (Evidenzbasierte) Trainingsprinzipien. In A. Güllich & M. Krüger (Hrsg.), *Bewegung, Training, Leistung und Gesundheit* (S. 1–17). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-53386-4_45-1

Döring, N. & Bortz, J. (2016). *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-41089-5

Dufaug, A., Barthod, C., Goujon, L. & Marechal, L. (2020). New joint analysis of electromyography spectrum and amplitude-based methods towards real-time muscular fatigue evaluation during a simulated surgical procedure: A pilot analysis on the statistical significance. *Medical engineering & physics*, *79*, 1–9. https://doi.org/10.1016/j.medengphy.2020.01.017

Dupuy, A., Campbell, M. J., Harrison, A. J. & Toth, A. J. (2024). On the necessity for biomechanics research in esports. *Sports biomechanics*, 1–13. https://doi.org/10.1080/14763141.2024.2354440

Ekefjärd, S., Piussi, R. & Hamrin Senorski, E. (2024). Physical symptoms among professional gamers within eSports, a survey study. *BMC sports science, medicine & rehabilitation*, *16*(1), 18. https://doi.org/10.1186/s13102-024-00810-y

ESL Gaming GmbH. (2024). *The Ultimate Counter-Strike Competition: Game Specific Rules*. https://pro.eslgaming.com/tour/cs/#rules

Fathuldeen, A., Alshammiri, M. F. & Abdulmohsen, A. (2023). Prevalence and Awareness of Musculoskeletal Injuries Associated With Competitive Video Gaming in Saudi Arabia. *Cureus*, *15*(4), e37733. https://doi.org/10.7759/cureus.37733

Flick, U. (2011). *Triangulation*. VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-92864-7

Forman, G. N., Melchiorre, L. P. & Holmes, M. W. R. (2024). Impact of repetitive mouse clicking on forearm muscle fatigue and mouse aiming performance.

Applied ergonomics, *118*, 104284. https://doi.org/10.1016/j.apergo.2024.104284

Forman, G. N., Sonne, M. W., Kociolek, A. M., Gabriel, D. A. & Holmes, M. W. R. (2022). Influence of muscle fatigue on motor task performance of the hand and wrist: A systematic review. *Human movement science*, *81*, 102912. https://doi.org/10.1016/j.humov.2021.102912

Franks, R. R., King, D., Bodine, W., Chisari, E., Heller, A., Jamal, F., Luksch, J., Quinn, K., Singh, R. & Solomon, M. (2022). AOASM Position Statement on Esports, Active Video Gaming, and the Role of the Sports Medicine Physician. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine*, *32*(3), e221-e229. https://doi.org/10.1097/JSM.0000000000001034

Frech, A. (2012). Healthy Behavior Trajectories between Adolescence and Young Adulthood. *Advances in life course research*, *17*(2), 59–68. https://doi.org/10.1016/j.alcr.2012.01.003

Freitas, B. D. A. (2023). The Infancy of the Esports Industry as a Risk to its Sponsors. *Scientific Annals of Economics and Business*, *70*(3), 421–458. https://doi.org/10.47743/saeb-2023-0030

Funk, D. C., Pizzo, A. D. & Baker, B. J. (2018). eSport management: Embracing eSport education and research opportunities. *Sport Management Review*, *21*(1), 7–13. https://doi.org/10.1016/j.smr.2017.07.008

Gallagher, S. (2022). *Musculoskeletal Disorders: The Fatigue Failure Mechanism*. John Wiley & Sons Incorporated. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=7001294

Gallagher, S. & Schall, M. C. (2017). Musculoskeletal disorders as a fatigue failure process: evidence, implications and research needs. *Ergonomics*, *60*(2), 255–269. https://doi.org/10.1080/00140139.2016.1208848

game. (2024). *Jahresreport der deutschen Games-Branche*. https://www.game.de/publikationen/jahresreport-2024/

Geronilla, K. B., Miller, G. R., Mowrey, K. F., Wu, J. Z., Kashon, M. L., Brumbaugh, K., Reynolds, J., Hubbs, A. & Cutlip, R. G. (2003). Dynamic force responses of skeletal muscle during stretch-shortening cycles. *European journal of applied physiology*, *90*(1-2), 144–153. https://doi.org/10.1007/s00421-003-0849-8

Giles, G. E., Cantelon, J. A., Eddy, M. D., Brunyé, T. T., Urry, H. L., Taylor, H. A., Mahoney, C. R. & Kanarek, R. B. (2018). Cognitive reappraisal reduces perceived exertion during endurance exercise. *Motivation and Emotion*, *42*(4), 482–496. https://doi.org/10.1007/s11031-018-9697-z

Hakala, P. T., Rimpelä, A. H., Saarni, L. A. & Salminen, J. J. (2006). Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. *European journal of public health*, *16*(5), 536–541. https://doi.org/10.1093/eurpub/ckl025

Hanphitakphong, P., Thawinchai, N. & Poomsalood, S. (2021). Effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles in school students aged between 10-18 years. *Cogent Engineering*, *8*(1), Artikel 1890368. https://doi.org/10.1080/23311916.2021.1890368

Hartmann, B. (2022). Kompatibilität und Belastungs-Beanspruchungs-Konzept aus der Sicht der Arbeitsmedizin. *Zeitschrift für Arbeitswissenschaft*, *76*(3), 327–332. https://doi.org/10.1007/s41449-021-00256-9

He, Y., Tran, C., Jiang, J., Burghardt, K., Ferrara, E., Zheleva, E. & Lerman, K. (2021). Heterogeneous Effects of Software Patches in a Multiplayer Online Battle Arena Game. In A. Fowler, J. Pirker, A. A. Canossa, A. A. Arya & C. Harteveld (Hrsg.), *The 16th International Conference on the Foundations of Digital Games (FDG) 2021* (S. 1–9). ACM. https://doi.org/10.1145/3472538.3472550

Hellig, T. (2019). *Musculoskeletal exertion under consideration of the interaction of working postures* [, RWTH Aachen University]. DataCite.

Hilfiker, R. (2008). Schmerzintensität messen. *physiopraxis*, *6*(11/12), 46–47. https://doi.org/10.1055/s-0032-1308158

Holgado, D., Mesquida, C. & Román-Caballero, R. (2023). Assessing the Evidential Value of Mental Fatigue and Exercise Research. *Sports Medicine*, *53*(12), 2293–2307. https://doi.org/10.1007/s40279-023-01926-w

Holzgreve, F., Fraeulin, L., Haenel, J., Schmidt, H., Bader, A., Frei, M., Groneberg, D. A., Ohlendorf, D. & van Mark, A. (2021). Office work and stretch training (OST) study: effects on the prevalence of musculoskeletal diseases and gender differences: a non-randomised control study. *Bmj Open*, *11*(5), e044453. https://doi.org/10.1136/bmjopen-2020-044453

Holzgreve, F., Schulte, L., Oremek, G. & Ohlendorf, D. (2023). Allgemeine und arbeitsplatzbezogene Risikofaktoren von Muskel-Skelett-Erkrankungen und deren Bestimmungsmethoden. *Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie*, *73*(4), 182–189. https://doi.org/10.1007/s40664-023-00500-5

Hupke, M., van den Broek, K. & Kudasz., F. (2022). *Psychosocial risks and workers health.* European Agency for Safety and Health at Work. https://oshwiki.osha.europa.eu/en/themes/psychosocial-risks-and-workers-health

Huysmans, M. A., Hoozemans, M. J. M., van der Beek, A. J., Looze, M. P. de & van Dieën, J. H. (2008). Fatigue effects on tracking performance and muscle activity. *Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology*, *18*(3), 410–419. https://doi.org/10.1016/j.jelekin.2006.11.003

International Olympic Committee. (2024). *IOC enters a new era with the creation of Olympic Esports Games - first Games in 2025 in Saudi Arabia*. https://www.olympics.com/ioc/news/ioc-enters-a-new-era-with-the-creation-of-olympic-esports-games-first-games-in-2025-in-saudi-arabia

Jalink, M. B., Heineman, E., Pierie, J.-P. E. N. & ten Cate Hoedemaker, Henk O (2014). Nintendo related injuries and other problems: review. *BMJ (Clinical research ed.)*, *349*, g7267. https://doi.org/10.1136/bmj.g7267

Jenny, S. E., Besombes, N., Brock, T., Cote, A. C. & Scholz, T. M. (Hrsg.). (2025). *Routledge International Handbooks*. *Routledge Handbook of Esports*. Routledge.

Jenny, S. E., Manning, R. D., Keiper, M. C. & Olrich, T. W. (2017). Virtual(ly) Athletes: Where eSports Fit Within the Definition of "Sport". *Quest*, *69*(1), 1–18. https://doi.org/10.1080/00336297.2016.1144517

Judge, T. A. & Bono, J. E. (2001). Relationship of core self-evaluations traits—self-esteem, generalized self-efficacy, locus of control, and emotional stability—with job satisfaction and job performance: A meta-analysis. *Journal of Applied Psychology*, *86*(1), 80–92. https://doi.org/10.1037/0021-9010.86.1.80

Kaya Aytutuldu, G., Birinci, T. & Tarakcı, E. (2022). Musculoskeletal pain and its relation to individual and work-related factors: a cross-sectional study among Turkish office workers who work using computers. *International journal of* *occupational safety and ergonomics : JOSE*, *28*(2), 790–797. https://doi.org/10.1080/10803548.2020.1827528

Kica, A., La Manna, A., O'Donnell, L., Paolillo, T. & Claypool, M. (2016). Nerfs, Buffs and Bugs - Analysis of the Impact of Patching on League of Legends. In *2016 International Conference on Collaboration Technologies and Systems (CTS)* (S. 128–135). IEEE. https://doi.org/10.1109/CTS.2016.0039

Kleinert, J. (2006). Adjektivliste zur Erfassung der Wahrgenommenen Körperlichen Verfassung (WKV). *Zeitschrift für Sportpsychologie*, *13*(4), 156–164. https://doi.org/10.1026/1612-5010.13.4.156

Kok, J. de, Vroonhof, P., Snijders, J., Roullis, G., Clarke, M., Peereboom, K., van Dorst, P. & Isusi, I. (2019). *Work-related musculoskeletal disorders: Prevalence, costs and demographics in the EU.* Publications Office of the European Union. https://osha.europa.eu/en/publications/work-related-musculoskeletal-disorders-prevalence-costs-and-demographics-eu/view

Laborde, S., Mosley, E. & Thayer, J. F. (2017). Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research - Recommendations for Experiment Planning, Data Analysis, and Data Reporting. *Frontiers in psychology*, *8*, 213. https://doi.org/10.3389/fpsyg.2017.00213

Las Heras, B. de, Li, O., Rodrigues, L., Nepveu, J.-F. & Roig, M. (2020). Exercise Improves Video Game Performance: A Win-Win Situation. *Medicine and science in sports and exercise*, *52*(7), 1595–1602. https://doi.org/10.1249/MSS.0000000000002277

Laurig, W. (2015). *Belastungs-Beanpruchungs-Konzept und Gefährdungsbeurteilung*. http://www.ergonassist.de/GKH/GKH_Belastg_Beanspruchg_Gefaehrdg.html

Law, A., Ho, G. & Moore, M. (2023). Care of the Esports Athlete. *Current sports medicine reports*, *22*(6), 224–229. https://doi.org/10.1249/JSR.0000000000001077

Lee, K. A., Hicks, G. & Nino-Murcia, G. (1991). Validity and reliability of a scale to assess fatigue. *Psychiatry Research*, *36*(3), 291–298. https://doi.org/10.1016/0165-1781(91)90027-M

Leis, O. & Lautenbach, F. (2020). Psychological and physiological stress in non-competitive and competitive esports settings: A systematic review. *Psychology* *of Sport and Exercise*, *51*, 101738. https://doi.org/10.1016/j.psychsport.2020.101738

Leis, O., Lautenbach, F., Birch, P. D. & Elbe, A.-M. (2022). Stressors, associated responses, and coping strategies in professional esports players: A qualitative study(1). https://www.ijesports.org/article/76/html

Leis, O., Sharpe, B. T., Pelikan, V., Fritsch, J., Nicholls, A. R. & Poulus, D. (2024). Stressors and coping strategies in esports: a systematic review. *International Review of Sport and Exercise Psychology*, 1–31. https://doi.org/10.1080/1750984X.2024.2386528

Li, Z., Yang, G., Khan, M., Stone, D., Woo, S. L. Y. & Wang, J. H. C. (2004). Inflammatory response of human tendon fibroblasts to cyclic mechanical stretching. *The American journal of sports medicine*, *32*(2), 435–440. https://doi.org/10.1177/0095399703258680

Lindberg, L., Nielsen, S. B., Damgaard, M., Sloth, O. R., Rathleff, M. S. & Straszek, C. L. (2020). Musculoskeletal pain is common in competitive gaming: a cross-sectional study among Danish esports athletes. *BMJ open sport & exercise medicine*, *6*(1). https://doi.org/10.1136/bmjsem-2020-000799

Luttmann, A., Jäger, M. & Laurig, W. (2000). Electromyographical indication of muscular fatigue in occupational field studies. *International Journal of Industrial Ergonomics*, *25*(6), 645–660. https://doi.org/10.1016/S0169-8141(99)00053-0

Manci, E., Theobald, P., Toth, A., Campbell, M., DiFrancisco-Donoghue, J., Gebel, A., Müller, N. G., Gronwald, T. & Herold, F. (2024). It's about timing: how density can benefit future research on the optimal dosage of acute physical exercise breaks in esports. *BMJ open sport & exercise medicine*, *10*(4), e002243. https://doi.org/10.1136/bmjsem-2024-002243

Mancı, E., Gençtürk, U., Günay, E., Güdücü, Ç., Herold, F. & Bediz, C. Ş. (2024). The influence of acute sprint exercise on cognition, gaming performance, and cortical hemodynamics in esports players and age-matched controls. *Current Psychology*, *43*(22), 19643–19654. https://doi.org/10.1007/s12144-024-05750-x

Mao, E. (2023). The Incentive Effects of Tournaments and Peer Effects in Team Production: Evidence from Esports. *Journal of Sports Economics*, *24*(2), 174–192. https://doi.org/10.1177/15270025221113033

Mazaheri-Tehrani, S., Arefian, M., Abhari, A. P., Riahi, R., Vahdatpour, B., Baradaran Mahdavi, S. & Kelishadi, R. (2023). Sedentary behavior and neck pain in adults: A systematic review and meta-analysis. *Preventive medicine*, *175*, 107711. https://doi.org/10.1016/j.ypmed.2023.107711

McCowan, T. C. (1981). Space-Invaders wrist. *The New England journal of medicine*, *304*(22), 1368. https://doi.org/10.1056/nejm198105283042228

McLeod, C. M., Xue, H. & Newman, J. I. (2022). Opportunity and inequality in the emerging esports labor market. *International Review for the Sociology of Sport*, *57*(8), 1279–1300. https://doi.org/10.1177/10126902211064093

McNulty, C., Jenny, S. E., Leis, O., Poulus, D., Sondergeld, P. & Nicholson, M. (2023). Physical Exercise and Performance in Esports Players: An Initial Systematic Review. *Journal of Electronic Gaming and Esports*, *1*(1), Article 14. https://doi.org/10.1123/jege.2022-0014

Meijman, T. F. & Mulder, G. (1998). Psychological Aspects of Workload. In P. J. D. Drenth, H. Thierry & de Wollf C. J. (Hrsg.), *A Handbook of Work and Organizational Psychology: : Volume 2: Work Psychology* (2. ed., Bd. 2, S. 5–33). Psychology Press.

Migliore, L. & Beckman, K. (2021). Upper Extremity Disorders in Esports. In L. Migliore, C. McGee & M. N. Moore (Hrsg.), *Handbook of Esports Medicine* (S. 17–70). Springer International Publishing. https://doi.org/10.1007/978-3-030-73610-1_2

Migliore, L., McGee, C. & Moore, M. N. (Hrsg.). (2021). *Handbook of Esports Medicine*. Springer International Publishing. https://doi.org/10.1007/978-3-030-73610-1

Millar, N. L., Silbernagel, K. G., Thorborg, K., Kirwan, P. D., Galatz, L. M., Abrams, G. D., Murrell, G. A. C., McInnes, I. B. & Rodeo, S. A. (2021). Tendinopathy. *Nature reviews. Disease primers*, *7*(1), 1. https://doi.org/10.1038/s41572-020-00234-1

Mohammadipour, F., Pourranjbar, M., Naderi, S. & Rafie, F. (2018). Work-related Musculoskeletal Disorders in Iranian Office Workers: Prevalence and Risk Factors. *Journal of medicine and life*, *11*(4), 328–333. https://doi.org/10.25122/jml-2018-0054

Monma, T., Matsui, T., Koyama, S., Ueno, H., Kagesawa, J., Oba, C., Nakamura, K., Takagi, H. & Takeda, F. (2024). Prevalence and Associated Factors of

Physical Complaints Among Japanese Esports Players: A Cross-Sectional Study. *Cureus*, *16*(8), e66496. https://doi.org/10.7759/cureus.66496

Morse, K. F., Fine, P. A. & Friedlander, K. J. (2021). Creativity and Leisure During COVID-19: Examining the Relationship Between Leisure Activities, Motivations, and Psychological Well-Being. *Frontiers in psychology*, *12*, 609967. https://doi.org/10.3389/fpsyg.2021.609967

Mosley, E. & Laborde, S. (2024). A scoping review of heart rate variability in sport and exercise psychology. *International Review of Sport and Exercise Psychology*, *17*(2), 773–847. https://doi.org/10.1080/1750984X.2022.2092884

Mousavizadeh, R., Waugh, C. M., McCormack, R. G., Cairns, B. E. & Scott, A. (2024). MRGPRX2-mediated mast cell activation by substance P from overloaded human tenocytes induces inflammatory and degenerative responses in tendons. *Scientific reports*, *14*(1), 13540. https://doi.org/10.1038/s41598-024-64222-1

Müller, C., Winter, C. & Rosenbaum, D. (2010). Aktuelle objektive Messverfahren zur Erfassung körperlicher Aktivität im Vergleich zu subjektiven Erhebungsmethoden: Current Objective Techniques for Physical Activity Assessment in Comparison with Subjective Methods. *Deutsche Zeitschrift für Sportmedizin*(61), Artikel 1.

Nagorsky, E. & Wiemeyer, J. (2020). The structure of performance and training in esports. *PloS one*, *15*(8), e0237584. https://doi.org/10.1371/journal.pone.0237584

National Academies Press. (2020). *Selected Health Conditions and Likelihood of Improvement with Treatment.* https://doi.org/10.17226/25662

Newzoo. (2023). *Global Games Market Report: Free Version*. https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version

Newzoo. (2024a). *Global Gamer Study 2024: How consumers engage with games today*. https://investgame.net/wp-content/uploads/2024/07/Newzoo_How-consumers-engaged-with-games-in-2024_Global-Gamer-Study-2024.pdf

Newzoo. (2024b). *Global Games Market Report: Free Version*. https://newzoo.com/resources/trend-reports/newzoos-global-games-market-report-2024-free-version

Nicholson, M., Thompson, C., Poulus, D., Pavey, T., Robergs, R., Kelly, V. & McNulty, C. (2024). Physical Activity and Self-Determination towards Exercise among Esports Athletes. *Sports medicine - open*, *10*(1), 40. https://doi.org/10.1186/s40798-024-00700-0

Pageaux, B. (2016). Perception of effort in Exercise Science: Definition, measurement and perspectives. *European journal of sport science*, *16*(8), 885–894. https://doi.org/10.1080/17461391.2016.1188992

Pageaux, B., Marcora, S. M., Rozand, V. & Lepers, R. (2015). Mental fatigue induced by prolonged self-regulation does not exacerbate central fatigue during subsequent whole-body endurance exercise. *Frontiers in human neuroscience*, *9*, 67. https://doi.org/10.3389/fnhum.2015.00067

Restaino, R. M., Holwerda, S. W., Credeur, D. P., Fadel, P. J. & Padilla, J. (2015). Impact of prolonged sitting on lower and upper limb micro- and macrovascular dilator function. *Experimental physiology*, *100*(7), 829–838. https://doi.org/10.1113/EP085238

Rightmire, Z. B., Agostinelli, P. J., Murrah, W. M., Roper, J. A., Roberts, M. D. & Sefton, J. M. (2024). Acute High-Intensity Interval Training Improves Esport Performance in Super Smash Brothers Ultimate Competitors. *Journal of Electronic Gaming and Esports*, *2*(1). https://doi.org/10.1123/jege.2023-0031

Riot Games. (2024). *OFFICIAL ERL RULEBOOK v2.0 2025 SEASON*. https://cdn.sanity.io/files/dsfx7636/news/f068037e8869f9ec647a2caef1b56f50f3dd830f.pdf

Rohmert, W. (1984). Das Belastungs-Beanspruchungs-Konzept;. *Zeitschrift für Arbeitswissenschaft*, *38*(4), 193–200.

Rohmert, W. (1986). Ergonomics: concept of work, stress and strain. *Applied Psychology*, *35*(2), 159–180. https://doi.org/10.1111/j.1464-0597.1986.tb00911.x

Rothe, I., Adolph, L., Beermann, B., Schütte, M., Windel, A., Grewer, A., Lenhardt, U., Michel, J., Thomson, B. & Formazin, M. (2017). *Psychische Gesundheit in der Arbeitswelt.* https://doi.org/10.21934/baua:bericht20170421

Rudolf, K., Bickmann, P., Froböse, I., Tholl, C., Wechsler, K. & Grieben, C. (2020). Demographics and Health Behavior of Video Game and eSports Players in Germany: The eSports Study 2019. *International journal of environmental research and public health*, *17*(6). https://doi.org/10.3390/ijerph17061870

Rudolf, K., Soffner, M., Bickmann, P., Froböse, I., Tholl, C., Wechsler, K. & Grieben, C. (2022). Media Consumption, Stress and Wellbeing of Video Game and eSports Players in Germany: The eSports Study 2020. *Frontiers in sports and active living*, *4*, 665604. https://doi.org/10.3389/fspor.2022.665604

Schlick, C., Bruder, R. & Luczak, H. (2018). *Arbeitswissenschaft*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-56037-2

Schmidt, K., Friedrichs, P., Cornelsen, H. C., Schmidt, P. & Tischer, T. (2021). *Musculoskeletal disorders among children and young people: prevalence, risk factors, preventive measures.* Publications Office of the European Union. https://healthy-workplaces.eu/en/publications/musculoskeletal-disorders-among-children-and-young-people-prevalence-risk-factors-preventive-measures

Scholz, T. M. & Nothelfer, N. (2022). *Esports: Background analysis : study requested by the CULT committee*. European Union. https://op.europa.eu/o/opportal-service/download-handler?identifier=eb782f76-d263-11ec-a95f-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part= https://doi.org/10.2861/544672

Schweizer, M. L., Braun, B. I. & Milstone, A. M. (2016). Research Methods in Healthcare Epidemiology and Antimicrobial Stewardship—Quasi-Experimental Designs. *Infection Control & Hospital Epidemiology*, *37*(10), 1135–1140. https://doi.org/10.1017/ice.2016.117

Shariat, A., Cleland, J. A., Danaee, M., Alizadeh, R., Sangelaji, B., Kargarfard, M., Ansari, N. N., Sepehr, F. H. & Tamrin, S. B. M. (2018). Borg CR-10 scale as a new approach to monitoring office exercise training. *Work (Reading, Mass.)*, *60*(4), 549–554. https://doi.org/10.3233/WOR-182762

Sharpe, B. T., Obine, E. A. C., Birch, P. D. J., Pocock, C. & Moore, L. J. (2024). Performance breakdown under pressure among esports competitors. *Sport Exercise and Performance Psychology*, *13*(1), 89–109. https://doi.org/10.1037/spy0000337

Silva, G. R., Rodarti Pitangui, A. C., Andrade Xavier, M. K., Valois Correia-Junior, M. A. & Araujo, R. C. de (2016). Prevalence of musculoskeletal pain in adolescents and association with computer and videogame use. *Jornal de pediatria*, *92*(2), 188–196. https://doi.org/10.1016/j.jped.2015.06.006

Smith, N. (4. März 2022). Inside ‘contract hell’: Esports players say predatory contracts run ‘rampant’. *The Washington Post,* 2022. https://www.washingtonpost.com/video-games/esports/2022/03/04/esports-player-contracts/

Soendenbroe, C., Dahl, C. L., Meulengracht, C., Tamáš, M., Svensson, R. B., Schjerling, P., Kjaer, M., Andersen, J. L. & Mackey, A. L. (2022). Preserved stem cell content and innervation profile of elderly human skeletal muscle with lifelong recreational exercise. *The Journal of physiology*, *600*(8), 1969–1989. https://doi.org/10.1113/JP282677

Soffner, M., Bickmann, P., Tholl, C. & Froböse, I. (2023). Dietary behavior of video game players and esports players in Germany: a cross-sectional study. *Journal of health, population, and nutrition*, *42*(1), 29. https://doi.org/10.1186/s41043-023-00373-7

Sonnentag, S. & Frese, M. (2012). Stress in Organizations. In I. Weiner (Hrsg.), *Handbook of Psychology, Second Edition.* Wiley. https://doi.org/10.1002/9781118133880.hop212021

Statista Market Insights. (2024). *Videospiele - Weltweit*. https://de.statista.com/outlook/dmo/digitale-medien/videospiele/weltweit#umsatz

Statistisches Bundesamt. (2024). *Krankheitskosten, Krankheitskosten je Einwohner: Deutschland, Jahre, Krankheitsdiagnosen (ICD-10): 2015-2020*. https://www-genesis.destatis.de/datenbank/online/statistic/23631/table/23631-0001/

Stephenson, S. D., Kocan, J. W., Vinod, A. V., Kluczynski, M. A. & Bisson, L. J. (2021). A Comprehensive Summary of Systematic Reviews on Sports Injury Prevention Strategies. *Orthopaedic journal of sports medicine*, *9*(10), 23259671211035776. https://doi.org/10.1177/23259671211035776

Stillman, C. M., Esteban-Cornejo, I., Brown, B., Bender, C. M. & Erickson, K. I. (2020). Effects of Exercise on Brain and Cognition Across Age Groups and Health States. *Trends in neurosciences*, *43*(7), 533–543. https://doi.org/10.1016/j.tins.2020.04.010

Takala, E.-P., Pehkonen, I., Forsman, M., Hansson, G.-Å., Mathiassen, S. E [Svend Erik], Neumann, W. P., Sjøgaard, G., Veiersted, K. B., Westgaard, R. H. & Winkel, J [Jörgen] (2010). Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scandinavian journal of work, environment & health*, *36*(1), 3–24. https://doi.org/10.5271/sjweh.2876

Tazawa, Y. & Okada, K. (2001). Physical signs associated with excessive television-game playing and sleep deprivation. *Pediatrics international : official journal of the Japan Pediatric Society*, *43*(6), 647–650. https://doi.org/10.1046/j.1442-200x.2001.01466.x

Torsheim, T., Eriksson, L., Schnohr, C. W., Hansen, F., Bjarnason, T. & Välimaa, R. (2010). Screen-based activities and physical complaints among adolescents from the Nordic countries. *BMC public health*, *10*, 324. https://doi.org/10.1186/1471-2458-10-324

Turner, C., Goubault, E., Maso, F. D., Begon, M. & Verdugo, F. (2023). The influence of proximal motor strategies on pianists' upper-limb movement variability. *Human movement science*, *90*, 103110. https://doi.org/10.1016/j.humov.2023.103110

van Cutsem, J., Marcora, S., Pauw, K. de, Bailey, S., Meeusen, R. & Roelands, B. (2017). The Effects of Mental Fatigue on Physical Performance: A Systematic Review. *Sports Medicine*, *47*(8), 1569–1588. https://doi.org/10.1007/s40279-016-0672-0

Viana, R. B., Oliveira, V. N. de, Dankel, S. J., Loenneke, J. P., Abe, T., Da Silva, W. F., Morais, N. S., Vancini, R. L., Andrade, M. S. & Lira, C. A. B. de (2021). The effects of exergames on muscle strength: A systematic review and meta-analysis. *Scandinavian journal of medicine & science in sports*, *31*(8), 1592–1611. https://doi.org/10.1111/sms.13964

Vila Pouca, M. C. P., Parente, M. P. L., Jorge, R. M. N. & Ashton-Miller, J. A. (2021). Injuries in Muscle-Tendon-Bone Units: A Systematic Review Considering the Role of Passive Tissue Fatigue. *Orthopaedic journal of sports medicine*, *9*(8), 23259671211020731. https://doi.org/10.1177/23259671211020731

Wang, D., Tang, L., Wu, H. & Gu, D. (2019). Analysis of the effect of overusing thumbs on smartphone games. *Journal of International Medical Research*, *47*(12), 6244–6253. https://doi.org/10.1177/0300060519881016

Waongenngarm, P., Areerak, K. & Janwantanakul, P. (2018). The effects of breaks on low back pain, discomfort, and work productivity in office workers: A systematic review of randomized and non-randomized controlled trials.

Applied ergonomics, *68*, 230–239. https://doi.org/10.1016/j.apergo.2017.12.003

Willems, M. E. & Stauber, W. T. (2000). Effect of resistance training on muscle fatigue and recovery in intact rats. *Medicine and science in sports and exercise*, *32*(11), 1887–1893. https://doi.org/10.1097/00005768-200011000-00011

Winkel, J [J.] & Mathiassen, S. E [S. E.] (1994). Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics*, *37*(6), 979–988. https://doi.org/10.1080/00140139408963711

Wisdom, K. M., Delp, S. L. & Kuhl, E. (2015). Use it or lose it: multiscale skeletal muscle adaptation to mechanical stimuli. *Biomechanics and modeling in mechanobiology*, *14*(2), 195–215. https://doi.org/10.1007/s10237-014-0607-3

Wollesen, B., Tholl, C. & Thiel, A. (2025). Esports: Scientific significance, and the debate on its status as sport. *German Journal of Exercise and Sport Research.* Vorab-Onlinepublikation. https://doi.org/10.1007/s12662-025-01054-9

World Health Organization. (2020). *WHO Guidelines on Physical Activity and Sedentary Behaviour: At a Glance* (1st ed.). World Health Organization. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=30478353

Yabe, Y., Hagiwara, Y., Sekiguchi, T., Momma, H., Tsuchiya, M., Kuroki, K., Kanazawa, K., Koide, M., Itaya, N., Itoi, E. & Nagatomi, R. (2018). Late bedtimes, short sleeping time, and longtime video-game playing are associated with low back pain in school-aged athletes. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*, *27*(5), 1112–1118. https://doi.org/10.1007/s00586-017-5177-5

Yassi, A. (1997). Repetitive strain injuries. *Lancet (London, England)*, *349*(9056), 943–947. https://doi.org/10.1016/S0140-6736(96)07221-2

Zisopoulou, T. & Varvogli, L. (2023). Stress Management Methods in Children and Adolescents: Past, Present, and Future. *Hormone research in paediatrics*, *96*(1), 97–107. https://doi.org/10.1159/000526946

VII. Anhang

A. Belastungs-Beanspruchungsmodell des E-Sports

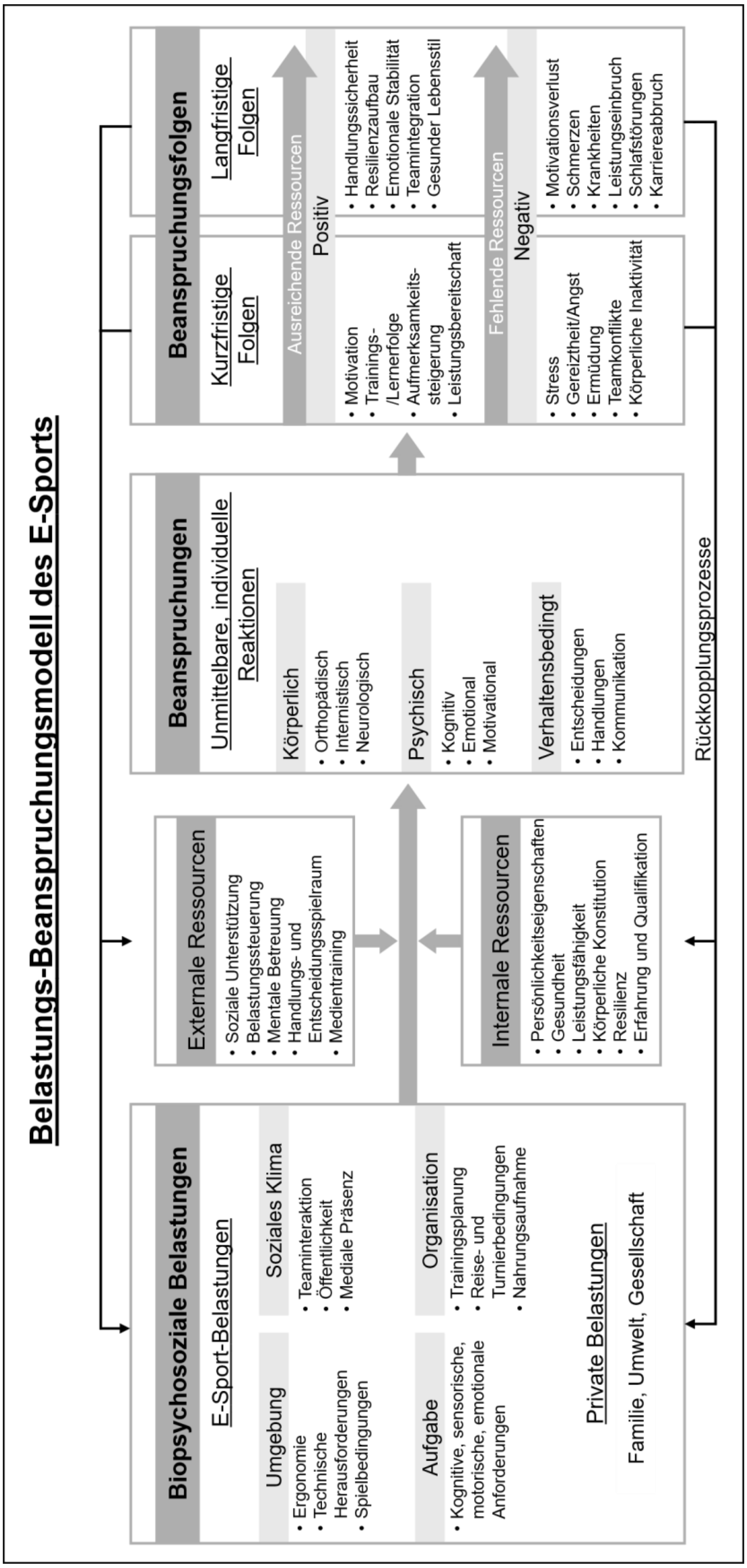

Abbildung 6: Große Darstellung des Belastungs-Beanspruchungsmodell des E-Sports, angelehnt an das erweiterte Belastungs-Beanspruchungsmodell nach DIN (2018) (eigene Darstellung).

B. Studie I: Musculoskeletal disorders in video gamers – a systematic review

Tholl *et al. BMC Musculoskeletal Disorders* (2022) 23:678
https://doi.org/10.1186/s12891-022-05614-0

BMC Musculoskeletal Disorders

RESEARCH Open Access

Musculoskeletal disorders in video gamers – a systematic review

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Abstract

Background: Video gaming is a recreational activity with yearly increasing popularity. It is mostly a sedentary behavior combined with repetitive movements of the upper limbs. If performed excessively, these movements may promote strain injuries and a sedentary lifestyle is one of the contributing factors to musculoskeletal disorders. Therefore, a systematic review was conducted to evaluate if video gaming negatively affects the musculoskeletal system of video gamers.

Methods: PubMed, Web of Science and The Cochrane Library were systematically searched in order to identify relevant peer reviewed original articles in English published between 2000 and 2021. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was used for the analysis. Studies were included when they contained investigations of changes of the musculoskeletal system due to video gaming in healthy individuals. Studies with participants older than 60 years or solely psychological, social or cardiovascular outcomes were excluded. An adapted version of the Newcastle–Ottawa Scale was used for the risk of bias analysis.

Results: Sixteen observational studies involving a total of 62,987 participants met the inclusion criteria. A majority (11) of the studies reported statistical negative musculoskeletal changes due to video game playtime. Four studies did not report changes and one study found no effect of video game playtime on the musculoskeletal system. Out of the eleven studies, which demonstrated a negative impact of video game playtime on the musculoskeletal system, the most reported painful body parts were the neck ($n=4$), shoulder ($n=4$) and back ($n=3$). Ten studies reported odds ratios (OR) for the dependence of the appearance of musculoskeletal disorders on video game playtime. In eight studies OR were significantly increased (1.3—5.2).

Conclusion: Eleven out of twelve studies demonstrated a negative impact of video game playtime on the musculoskeletal system. In particular, excessive video game playtimes (> 3 h/day) seemed to be a predictor for the appearance of musculoskeletal disorders. Due to their great popularity across multiple generations, specific and tailored prevention and health promotion programs for video gamers need to be developed to counteract this important public health issue.

Keywords: Video gaming, MSD, Sedentary behavior, Physical pain, Esports

Introduction

Video gaming is one of the most popular recreational activities in the world [1]. In 2021 there were approximately 3.24 billion video gamers across the globe [2]. Alone Asia had 1.48 billion video gamers followed by Europe with a gaming audience of 715 million [2]. For the past several years the global video gaming industry has been growing. This has resulted in a global

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market amount close to USD 176 billion in 2021 [3]. This is almost twice as much as the market size of the global fitness and health club industry in 2019 [4], which is also a big part of the leisure activity sector. Therefore, video gaming cannot be seen as a short-term trend. However, it is important to keep in mind that especially the video gaming industry was one winner of the worldwide corona pandemic [5], because video gaming was not restricted by it. On the contrary, a lot of people had more leisure time and they spent their free time on video gaming in the corona lockdowns around the globe [5, 6], which was a perfect basis for an accumulation of sedentary time.

Video gaming is a screen-based activity, comparable to watching TV, working at the computer or using a smartphone. These kinds of activities are characterized by long, continuous sitting periods and physical inactivity [7]. Such sedentary behaviors are well-known risks of all-cause mortality and non-communicable diseases (NCD) [8, 9]. Watching TV is probably the most motionless undertaking of the screen-based activities, because it typically occurs in the evening time after dinner and a day of work [10]. Therefore, it is a kind of relaxing activity for most people [11]. Working at a computer, e.g., in the office on the other hand, often involves different kinds of sitting or standing positions, which are occasionally interrupted with short walks [12]. In addition to this seated position, video gaming requires fine motor skills to execute the gaming process [13, 14]. Therefore, it involves repetitive movement of the arms, wrists, hands and fingers in order to interact in the virtual environment [15], similar to some types of office work or even more intense activities [16]. Such movements, when performed continuously and without interruption, can lead to musculoskeletal disorders (MSDs), especially of the upper limbs [17, 18]. Moreover, MSDs are associated with physical inactivity, prolonged sitting and unilateral (sitting-) postures [19].

MSDs are a huge financial burden for healthcare systems in European countries. In 2016 Germany reported a loss of gross value added of EUR 30.4 billion because of musculoskeletal and connective tissue disorders [20]. This represents 1.0% of Germany's gross domestic product (GDP). The Swedish public health care reported approximately 20–30% of all visits were caused by MSDs and in France annual costs borne by enterprises exceed EUR 1 billion per year through MSDs [20]. Thus, in order to reduce health care costs and increase productivity, all countries should be interested in reducing the prevalence of MSDs. The generic term musculoskeletal disease includes several different kinds of conditions and diseases which affect bones, joints, muscles, and connective tissues [21]. For this reason, there is not only one but a variety of definitions of MSDs. Due to this diversity of definitions and thus a wide range of included diseases, the evaluation of MSDs lacks in a gold standard approach. Therefore, many different evaluation methods have been used. The most common ones are subjective (non-)standardized questionnaires, which are used to evaluate pain or discomforts in a defined time period [22]. Alternatively, (objective) clinical tests such the Finkelstein's test [23], have been used to evaluate single musculoskeletal issues. Thus, a wide variety of diseases and injuries have been listed and evaluated under the term MSD. The main physical causes for MSDs are lifestyle factors, being overweight, physical (non-)activity, postural problems, sports, heavy workload and ergonomic aspects [20, 24]. In addition, psychosocial, socioeconomic and environmental risk factors can be important [20]. Video gaming combines many of these factors like prolonged sitting-periods with a lack in physical activity, repetitive movements of the upper limbs and ergonomic burdens. Consequently, video gaming can be expected to lead to a higher risk for MSDs. The results of previous research have indicated this association [15, 25, 26]. Nevertheless, at this moment there is no overall-evidence of whether video gaming could affect the musculoskeletal system negatively.

The aim of this systematic review is to give an overview and review evidence of the extent to which video gaming influences the musculoskeletal system of gamers. For this purpose, in this systematic review it was investigated (1) whether video gaming negatively affects the musculoskeletal system of gamers, (2) to what extent the factor playtime influences musculoskeletal changes and (3) if there are certain body parts or specific tissues particularly affected. This is especially important if the imbalances in video gamer's health-behavior and special needs are to be identified. Moreover, these findings could be used for group specific prevention and rehabilitation recommendations to counteract these behaviors and improve the health of video gamers.

Methods

The protocol for this review was registered and published in the PROSPERO database (CRD42021220167) and was reported in accordance with the Preferred Reporting Items for Reviews and Meta-Analysis (PRISMA) [27].

Eligibility criteria

Studies had to be peer-reviewed, published between 2000 and 2021, and written in English. Participants in the studies had to be active video gamers.

All studies in which changes were investigated in the musculoskeletal system because of video gaming were of interest. This included issues of bones, cartilages, ligaments, tendons, muscles and tissues. Of special interest were negative changes in all human tissues and movements, for example range of motion, muscle tensions, pain syndromes and injuries. Reports about changes in the posture, muscle-nerve-connectivity or pain were included, as well as studies of the assessment of harms like cross-sectional, case–control or longitudinal studies. In addition, experimental studies like randomized controlled trials (RCTs) were also included.

Studies were excluded if they only contained psychological, social, or cardiovascular outcomes. Other reviews, meta-analysis and case reports were excluded for this review. Moreover, studies on overweight or obese people were excluded. Studies with elderly people (over 60 years) were excluded, along with studies which were restricted to specific musculoskeletal diseases or conditions or psychological, cognitive or social disorders.

Information sources and search strategy

Systematic electronic literature searches were undertaken of PubMed, Web of Science and Cochrane Library databases. Additionally, Google Scholar and reference lists of included studies were searched unsystematically. The first systematic electronic literature search was conducted on 08 October 2020 using PubMed and was updated on 01 December 2020 and 26 June 2021. For Web of Science the first search was conducted on 20 October 2020 and was updated on 02 December 2020 and 26 June 2021. The Cochrane Library was searched on 15 December 2020 and this was updated on 26 June 2021. Unsystematic searches of Google Scholar were conducted on 08 and 09 December 2020. Literature search strategies used medical subject headings (MeSH) and text words related to video gaming and musculoskeletal, injury or pain (Additional file 1).

Selection process

Author 1 and 2 independently screened titles and abstracts to include studies for full text analysis. The full text of the included studies were also independently reviewed by both authors to decide on inclusion or exclusion. Author 3 helped to find a consensus solution for the cases where there was a disagreement.

Data collection process

The systematic electronic literature search results were uploaded to Citavi 6 [28], a reference management program, to determine if there were duplicates. After that, literature was uploaded to Rayyan [29], an internet-based software which facilitates collaboration among reviewers during the study selection process. As the final step, a manually created excel sheet was used for data extraction from the included studies.

Study risk of bias assessment

An adapted version of the Newcastle–Ottawa Scale (NOS) for cross sectional studies [30, 31] was used to evaluate the risk of bias for the included studies. The scale included four items for selection (maximum 5 stars), one item for comparability (maximum 2 stars) and two items for outcome (maximum 3 stars). Therefore, each selected study was rated with a number from 0 (low quality) to 10 stars (high quality). By definition, a total of 7 or more stars indicated high quality, 4 to 6 stars indicated medium quality and 3 or less stars indicated low quality. Author 1 and 2 independently rated the studies and differences were resolved after a discussion. If there were further disagreements regarding study ratings Author 3 was involved in order to find a consensus solution.

Synthesis of results

It was anticipated that the identified studies in this systematic review would be heterogeneous in the study design. Therefore, the study results were synthesized narrative without any further statistical analysis. The narrative synthesis is based on the guidelines of the Centre for Reviews and Dissemination [32].

Results

Study selection

In Fig. 1: PRISMA Flow chart of study selection it is shown, that a total of 2017 articles were identified in three databases and Google Scholar. After removing duplicates (465), the titles and abstracts of the remaining 1552 studies were screened, of these 1526 studies did not fit with the inclusion criteria. Thus, a total of 26 full text articles were assessed for their eligibility. Finally, 16 eligible studies were included for the analysis.

Study characteristics

In Table 1: Study characteristics the characteristics are shown of the 16 included studies. A total of 62,987 participants from ten different countries and four continents were involved. The dominant population in eleven out of 16 included studies, were school aged kids and young adults aged between 5 to 20 years. Studies were mainly cross sectional, with the exception of one experimental study [26]. Out of the four possible video gaming devices (computers, consoles, handhelds, smartphones), seven studies included one device [25, 26, 33–37], three studies included two devices [38–40] and six studies included three or more devices [41–46]. Due to insufficient information, it is not possible to rule out that in two studies [37, 39] more than the indicated devices were used. Overall computers were the most commonly reported devices in 13 studies. The main body regions of reported

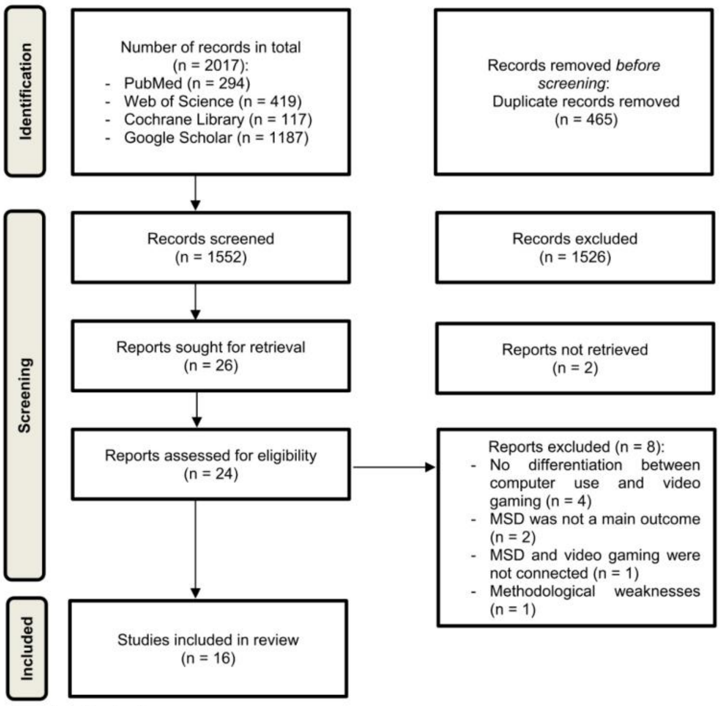

Fig. 1 PRISMA Flow chart of study selection

musculoskeletal pain were the neck ($n=7$), back ($n=6$), shoulders ($n=5$) and hands ($n=5$). As the evaluation method, in eleven of the studies self-designed non-standardized questionnaires were used [25, 36–39, 41–46]. Moreover, in two studies standardized questionnaires or checklists were used [33, 40] and one study each involved the use of electromyography (EMG) data and a visual analog scale [26], a clinical test and a partially standardized questionnaire [34] or only a partially standardized questionnaire [35].

Methodological quality

The risk of bias in all studies was assessed by an adapted version of the NOS (Additional file 2) and is shown in Table 2: Risk of bias in individual studies. Ten studies were of high quality with a score of 7 or higher [25, 34, 35, 38–40, 42, 44–46], five studies had a medium quality with a score between 5–6 [26, 33, 36, 41, 43], and one study got score of 1 [37] and was rated as low quality.

Results of individual studies

In Table 3: Results of individual studies, the individual results of the included studies are presented. In eleven studies a statistical negative impact was reported of video game playtime [3, 5–7, 9–11, 13, 14, 16, 17] on the musculoskeletal system. In four studies no impact was examined [2, 4, 8, 12] and in one study no effect was found of video game playtime on the musculoskeletal system [44]. Out of the eleven studies, in which a negative impact of video game playtime on the musculoskeletal system was demonstrated, the most reported painful body parts were the neck (n = 4), shoulder (n = 4) and back (n = 3). In ten of these studies odds ratios (OR) were calculated for the dependence of the appearance of musculoskeletal disorders on video game playtime [33–35, 38–40, 42–46]. In order to compare the group of video gamers, in eight studies non-gamers or subjects were used who played less than one hour a day of video games as a control group [33, 38, 39, 42–46]. The remaining studies only contained video gaming time < 2.25 h/day [34] or added every daily hour of video gaming [40] for an OR

Table 1 Study characteristics

First author (year), country	Study design	Population	Sample size (n)	Mean Age [yrs] (range), sex	Types of video gaming device[a]	Definition of MSD to identify changes[b]	Evaluation methods	Body regions of interest
Burke (2002), USA [41]	Cross sectional survey	School students	212	12.4 (5 – 18), 52% female	Computer, console, handheld	Presence of cumulative trauma disorders	Non-standardized questionnaire	Back, head, neck, wrist
DiFrancisco-Donoghue (2019), USA [37]	Cross sectional survey	College esport players	65	NR (18 – 22), NR	Computer, more CD	Reported pain in different body regions	Non-standardized questionnaire	Back, hand, neck, wrist
Hakala (2006), Finland [38]	Cross sectional survey	School students	6003	14-, 16-, 18-year-olds, 52.2% female	Computer, console	Neck-shoulder pain [NSP] or lower back pain [LBP] in the past 6 months	Non-standardized questionnaire	Back, neck, shoulder
Hellström (2015), Sweden [39]	Cross sectional survey	School students	7757	13–14-, 15–16-, 17–18-year-olds, 50% female	Computer, console, more CD	MSK pain during the past 3 months	Non-standardized questionnaire	Summarized[3]
Kang (2003), Korea [33]	Cross sectional survey	Gaming room visitors and college students	284	22.9 (17—29), 100% male	Computer	Presence, duration and severity of MSDs in upper limbs	NIOSH Criteria	Elbow, hand, neck, shoulder, wrist
Lindberg (2020), Denmark [25]	Cross sectional survey	Esport athletes	188	17.1 (15 – 35), 97.9% male	Computer	MSK pain during the previous week	Non-standardized questionnaire	Back, neck, shoulder
Ma (2019), China [34]	Cross sectional survey	Junior college students	500	17.9 (16—20), 60% male	Smartphone	(1) Positive test for de Quervain's disease (2) Limited wrist movements in the past 2 weeks	(1) Finkelstein's test (2) Partially standardized questionnaire	Wrist
Meziat-Filho (2017), Brazil [35]	Cross sectional survey	High school students	1102	16.8 (14 – 20), 53.3% female	Computer	Neck pain	Partially standardized questionnaire	Neck
Sekiguchi (2018a), Japan [42]	Cross sectional survey	School-aged athletes	6143	11^{Median} (6—15), 71.1% male	Computer, console, handheld, smartphone	Current pain in different body parts	Non-standardized questionnaire	Summarized[c]
Sekiguchi (2018b), Japan [43]	Cross sectional survey	Young baseball players	200	11 (9—12), 100% male	Computer, console, handheld, smartphone	Elbow or shoulder pain (in throwing arm) during the past 12 months	Non-standardized questionnaire	Elbow, shoulder
Silva (2016), Brazil [44]	Cross sectional survey	High school students	961	16.5 (14—19), 61.6% female	Computer, console, handheld	Presence of musculoskeletal pain in the last 6 months	Non-standardized questionnaire	Summarized[c]
Tazawa (2001), Japan [36]	Cross sectional survey	School students	1143	NR (6 – 11), 51.2% male	Console	Current or equivocal trapezius stiffness [MS] or MS and displacement of scapula [DS/MS]	Non-standardized questionnaire	Neck, shoulder

Table 1 (continued)

First author (year), country	Study design	Population	Sample size (n)	Mean Age [yrs] (range), sex	Types of video gaming device[a]	Definition of MSD to identify changes[b]	Evaluation methods	Body regions of interest
Torsheim (2010), Norway [40]	Cross sectional survey	School students in Nordic European countries	31,022	11-, 13-, 15-year-olds, 50% female	Computer, console	Physical complaints in past 6 months (backache and headache)	HBSC-Symptom checklist	Back, head
Wang (2019), China [26]	Experimental study	College students	12	24.2 (21—28), 58% female	Smartphone	(1) Muscle tension during experiment (2) Musculoskeletal discomfort	(1) Surface electro-myography (2) Visual analog	Hand
Xavier (2015), Brazil [46]	Cross sectional survey	High school students	954	16.5 (14—19), 61.4% female	Computer, console, handheld	Prevalence of headache	Non-standardized questionnaire	Head
Yabe (2018), Japan [45]	Cross sectional survey	School-aged athletes	6441	11[Median] (6—15), 71% male	Computer, console, handheld	Current pain in different body parts	Non-standardized questionnaire	Back

CD Cannot determine, *MSD* Musculoskeletal Disorder, *NR* Not reported, *Yrs* Years

[a] Indicated video gaming devices. Possible devices are computer, console, handheld and smartphone

[b] How MSDs are defined and/or how are changes determined

[c] Results of different body regions were collected independently but presented summarized

[Median] Median was indicated

Table 2 Risk of bias in individual studies

	Selection				Comparability	Outcome		Score
Study: first author (year)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Burke (2002) [41]			★	★	★★	★		5
DiFransiciso-Donoghue (2019) [37]					★			1
Hakala (2006) [38]	★	★	★	★	★★	★	★	8
Hellström (2015) [39]	★	★	★	★	★★	★	★	8
Kang (2003) [33]	★			★	★★	★	★	6
Lindberg (2020) [25]	★	★		★	★★	★	★	7
Ma (2019) [34]	★	★	★	★	★	★	★	7
Meziat-Filho (2017) [35]	★	★		★	★★	★	★	7
Sekiguchi (2018a) [42]	★	★		★	★★	★	★	7
Sekiguchi (2018b) [43]			★	★	★★	★	★	6
Silva (2016) [44]	★	★		★	★★	★	★	7
Tazawa (2001) [36]	★	★			★	★	★	5
Torsheim (2010) [40]	★	★		★★	★★	★	★	8
Wang (2019) [26]				★★		★★	★	5
Xavier (2015) [46]	★	★		★	★★	★	★	7
Yabe (2018) [45]	★	★		★	★★	★	★	7

1: Representativeness of the sample; 2: Justified and satisfactory sample size; 3: Non-respondents rate and characteristics; 4: Ascertainment of the exposure or risk factor (2 stars possible); 5: Comparability of groups based on study design or analysis (2 stars possible); 6: Assessment of the outcome (2 stars possible); 7: Statistical test description; Score: from 0 (low quality) to 10 stars (high quality)

calculation. In addition, the OR were based on different evaluation methods (Table 1: Study characteristics) and models which are described in the appendix (Additional file 3). A significant increase of the OR was reported in eight studies [33, 34, 38, 39, 42, 43, 45, 46]. In these studies, the OR ranged from 1.3 to 5.2.

Discussion

For the first time, the effect of video game playtime on the musculoskeletal system of video gamers was examined in a systematic review. Sixteen articles met the inclusion criteria of which ten were considered to have a low risk of bias. The main finding of this study is that video gaming could have a negative impact on the musculoskeletal system. With regard to this, video gaming duration was the decisive factor. The odds ratio of musculoskeletal disorders increased up to 5.2 for excessive video game playtime (>3 h/day).

The first research question can be confirmed, since in eleven out of 16 studies a negative impact of video game playtime on the musculoskeletal system was demonstrated. Seven of these studies were rated with a low risk of bias. The remaining four studies were rated with a moderate risk of bias. Hence, the overall bias of these eleven studies can be rated as low to medium. Consequently, the results confirm that video gaming negatively affects the musculoskeletal system of video gamers.

The second research question, whether excessive video game playtimes can be determined as a decisive factor in the development of MSDs, can also be confirmed. In eight studies a significant increase was reported of OR in individuals with high video game play times. More precisely, the probability of developing a MSD was significantly increased in subjects with video game playtimes of about two to three hours per day or more.

From the results the third research question can also be validated. Video gaming negatively affects different body parts. Out of the eleven studies, in which a negative impact of video gaming on the musculoskeletal system was demonstrated, the most negatively affected body parts caused by video gaming were the neck, shoulder and back. Consequently, video gamers who have excessive playtimes seem to be more vulnerable to developing pain in the neck, shoulder or back area.

Protective factors against MSDs

According to the results video game playtimes had a negative impact on the musculoskeletal system of video gamers. Moreover, this effect was amplified in individuals who had higher video game play times. However, this effect was not amplified in multivariate models (see Table 3: Results of individual studies). On the contrary, OR tended to decrease in more complex models [33, 38, 39, 42, 43, 45]. Therefore, some factors could have reduced the negative effect of video gaming on the

Table 3 Results of individual studies

First author (year), country	Mean video game playtime (h/week) or playtime categories	MSD affected by playtime?	Main findings	Comparison group for OR	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Burke (2002), USA [41]	3.3 h on Saturday	Not applicable	-Video gaming was a significant predictor for physical complaints (eyestrain, headache, back discomfort, wrist discomfort) -Non-educational games were a significant risk factor for wrist pain, backache and headache -Wrist discomfort was significantly influenced by joystick use and computer gameplay	No OR			
DiFrancisco-Donoghue (2019), USA [37]	NR	Not applicable	-The most reported complaints from esport players were eye fatigue (52%), followed by neck, back (41%), wrist (36%) and hand pain (30%)	No OR			
Hakala (2006), Finland [38]	≤1 h, 2-3 h, 4-5 h, > 5 h/day	Yes	-Risk of NSP increased only in the first model by playing digital games > 5 h/day -Digital gaming exceeding 5 h/day was a threshold for LBP in all three models	Not playing digital games at all or not daily	NSP: 2-3 h: 1.2 (0.9–1.4) 4-5 h: 1.1 (0.7–1.7) **> 5 h: 1.9 (1.2–3.1)** LBP: 2-3 h: 0.9 (0.7–1.2) 4-5 h: 1.1 (0.7–1.9) **> 5 h: 2.5 (1.5–4.1)**	NSP: 2-3 h: 1.0 (0.8–1.3) 4-5 h: 1.0 (0.6–1.6) > 5 h: 1.5 (0.9–2.6) LBP: 2-3 h: 0.9 (0.6–1.2) 4-5 h: 1.1 (0.7–1.9) **> 5 h: 2.3 (1.3–3.9)**	NSP: 2-3 h: 1.0 (0.8–1.3) 4-5 h: 1.0 (0.6–1.6) > 5 h: 1.4 (0.8–2.4) LBP: 2-3 h: 0.8 (0.6–1.1) 4-5 h: 0.9 (0.5–1.6) **> 5 h: 2.0 (1.1–3.5)**
Hellström (2015), Sweden [39]	NR	Yes	-Online multiplayer games were associated with MSK symptoms, but not in multivariate binary logistic regression -Gaming time on weekdays elevated the probability of MSK symptoms significantly	Non gamers vs. online gaming time on weekdays	**1.3 (1.1–1.3)**	Not applicable	Not applicable
Kang (2003), Korea [33]	< 1 h, 1-2 h, > 2 h/day	Yes	-MSD prevalence of the upper limbs in gaming room users was 26.8% Most frequently in neck (16.2%), shoulders (14.4%) and wrist (8.8%) -In bivariate analysis a non-significant trend between symptom prevalence of MSDs of the upper limbs and game room usage was observed -In multivariate analysis the duration of game room use was a significant determinant of MSDs in the whole upper limbs and especially in the neck, elbow, wrist and finger areas	Using game rooms < 1 h/day	Neck: 1-2 h: 1.7 (NR) **> 2 h: 2.8 (NR)** Shoulder 1-2 h: 0.8 (NR) > 2 h: 1.2 (NR) Elbow: 1-2 h: 1.1 (NR) > 2 h: 3.5 (NR) Wrist: 1-2 h: 1.5 (NR) **> 2 h: 3.4 (NR)** Finger: 1-2 h: 1.9 (NR) **> 2 h: 4.1 (NR)** Whole upper limbs: 1-2 h: 1.3 (NR) > 2 h: 1.9 (NR)	Neck: **1.8 (1.2–2.8)** Shoulder 1.1 (0.7–1.7) Elbow: **2.2 (1.1–4.7)** Wrist: **2.0 (1.1–3.3)** Finger: **2.3 (1.2–4.6)** Whole upper limbs: **1.5 (1.0–2.1)**	Not applicable

Table 3 (continued)

First author (year), country	Mean video game playtime (h/week) or playtime categories	MSD affected by playtime?	Main findings	Comparison group for OR	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Lindberg (2020), Denmark [25]	24.2 ± NR	Not applicable	-MSK pain was prevalent in esports athletes with 42.6% -The most reported body pain regions were the back (31.3%), neck (11.3%) and shoulders (11.3%) -MSK pain was significantly associated with less participation in esports-related training	No OR			
Ma (2019), China [34]	< 2 h, 2–3.9 h, 4–5.9 h, > 6 h/day	Yes	-Wrist position and smartphone playtime correlated significantly with DD -Students who spent over 2.25 h/day videogame playing had significantly higher risk of DD -Wrist positioning while smartphone gaming in dorsiflexion was more associated with DD than in function position	Mobile gaming > 2.25 h/day	**3.2 (2.2–4.6)**	Not applicable	Not applicable
Meziat-Filho (2017), Brazil [35]	< 2 h, ≥ 2 h/day	Yes	-The prevalence of acute neck pain while playing videogames < 2 h/day was 33.5%, for chronic neck pain it was 16.7% -The prevalence of acute neck pain while playing videogames ≥ 2 h/day was 31.0%, for chronic neck pain it was 13.5%	No OR			
Sekiguchi (2018a), Japan [42]	< 1 h, 1-2 h, 2-3 h, ≥ 3 h/day	Yes	-Playing videogames ≥ 3 h/day was significantly associated with MSK pain in crude analysis -The risk of MSK pain was increased by 39% in the group of high videogame time (≥ 3 h/day) in adjusted analysis -The group of high videogame time (≥ 3 h/day) was significantly associated with MSK pain in three or more locations	Video gaming < 1 h/day	1-2 h: 1.0 (0.9–1.2) 2-3 h: 1.1 (0.9–1.3) ≥ 3 h: **1.7 (1.3–2.0)**	1-2 h: 1.0 (0.9–1.2) 2-3 h: 1.1 (0.9–1.3) ≥ 3 h: **1.4 (1.1–1.7)**	Not applicable
Sekiguchi (2018b), Japan [43]	< 1 h, 1-2 h, 2-3 h, ≥ 3 h/day	Yes	-High videogame time (≥ 3 h/day) was significantly associated with elbow or shoulder pain in young baseball players -This association was also significant in multivariate analysis	Video gaming < 1 h/day	1-2 h: 1.5 (0.7–3.0) 2-3 h: 1.0 (0.4–2.7) ≥ 3 h: **5.2 (1.6–17.0)**	1-2 h: 1.4 (0.7–3.0) 2-3 h: 1.0 (0.4–2.6) ≥ 3 h: **5.2 (1.5–18.2)**	1-2 h: 1.4 (0.7–3.0) 2-3 h: 0.9 (0.3–2.5) ≥ 3 h: **4.8 (1.4–16.7)**

Table 3 (continued)

First author (year), country	Mean video game playtime (h/week) or playtime categories	MSD affected by playtime?	Main findings	Comparison group for OR	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Silva (2016), Brazil [44]	< 1 h, > 1 h/day	No	-The use of electronic games was reported by 2.9% of the adolescents as a triggering factor for at least one pain symptom -The use of electronic games was not associated with pain complaints in any of the surveyed body regions	Electronic gaming < 1 h/day	Cervical region: 1.0 (0.8–1.4) Scapular region: 1.0 (0.8–1.5) Thoracolumbar column: 0.9 (0.7–1.6) Upper limb: 1.1 (0.8–1.5)	Not applicable	Not applicable
Tazawa (2001), Japan [36]	0 h, 0.5 h, 1 h/day	Yes	-Excessive console gaming (> 1 h/day) caused greater frequency of MS than non-console playing (25.6% vs. 14.4%) -Console playing correlated highly significantly with MS	No OR			
Torsheim (2010), Norway [40]	$9.5^{a} \pm$ NR	Yes	-Computer gaming in boys was not correlated with either weekly backaches or headaches -Computer gaming in girls was significantly correlated with weekly backaches and headaches	Per added daily hour of computer gaming	Boys backache: 1.1 (1.0–1.1) Girls backache: 1.1 (1.0–1.1) Boys headache: 1.0 (1.0–1.1) Girls headache: 1.0 (1.0-.1.0)	Boys backache: 1.0 (1.0–1.1) Girls backache: 1.1 (1.0–1.1) Boys headache: 1.0 (1.0–1.1) Girls headache: 1.0 (1.0-.1.0)	Not applicable
Wang (2019), China [26]	NR	Not applicable	-Measured median frequency of thumb muscles were reduced significantly after 30 min of continuously playing smartphone games -Measured mean power frequency of thumb muscles were reduced significantly after 30 min of continuously playing smartphone games -VAS scores for discomfort increased significantly after 30 min of playing the smartphone game (score difference: 0 to 2)	No OR			
Xavier (2015), Brazil [46]	9.7 ± 15.5	Yes	-Excessive use of electronic devices (> 4 h/day) was associated with the presence of headaches -Excessive use of electronic games (> 4 h/day) was associated with the presence of headaches	Electronic gaming < 1 h/day	1.4 (0.4–5.7)	**1.9 (1.0–3.7)**	Not applicable

Table 3 (continued)

First author (year), country	Mean video game playtime (h/week) or playtime categories	MSD affected by playtime?	Main findings	Comparison group for OR	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Yabe (2018), Japan [45]	< 1 h, 1-2 h, 2-3 h, ≥ 3 h/day	Yes	-Videogame-playing time/day was significantly associated with the presence of lower back pain in both crude and adjusted model analyses -In all three models videogame-play times of ≥ 3 h/day were highly significantly associated with lower back pain	Video gaming < 1 h/day	1-2 h: 1.3 (1.0–1.7) 2-3 h: **1.6 (1.1–2.6)** ≥ 3 h: **2.8 (2.0–3.9)**	1-2 h: 1.3 (1.0–1.8) 2-3 h: 1.4 (1.0–2.0) ≥ 3 h: **2.0 (1.4–3.0)**	1-2 h: **1.4 (1.0–1.8)** 2-3 h: **1.5 (1.0–2.1)** ≥ 3 h: **2.2 (1.5–3.2)**

DD De Quervain's Disease, *LSB* Lower Back Pain, *MS* Muscle Stiffness, *MSD* Musculoskeletal Disorder, *MSK* Musculoskeletal, *NR* Not reported, *NSP* Neck-Shoulder Pain, *OR* Odds Ratio; **Bold** = Significant result ($p < .05$)

[a] The mean value was self-calculated

musculoskeletal system. In particular physical activity and age are well-known factors which can influence different health parameters [47–49] and may decrease OR. Physical activity and exercise are factors, which can counteract or prevent MSDs [49]. Moreover, in some studies the health benefits have already been shown of physical activity on the musculoskeletal system in sedentary populations, like video gamers [50]. Additionally, physical activity and even more sport therapy are typical and successful treatments used in the rehabilitation process of MSDs [51]. Consequently, physical activity and exercise could be protective factors which would reduce the negative health impacts of long continuous video game playtimes on the musculoskeletal system. Moreover, these interventions are necessary during the rehabilitation of MSDs if full health and performance status are to be regained of casual and professional video gamers. In addition to these physical factors, also sleeping habits, psychosocial balance, socioeconomic status, and environmental and ergonomic factors can either positively and negatively affect the musculoskeletal system [19, 24, 45]. For this reason, all these factors should be taken into mind, if excessive video game playtimes occur. In addition, video gamers need to be sensitized about the hazards of excessive and continuous video gaming.

Population and MSDs

The majority of the included populations were school aged kids and young adults in eleven of the 16 studies. In the remaining studies college students ($n=3$), esports athletes ($n=1$) and gaming room visitors ($n=1$) were observed. These populations were domiciled in ten different countries. Hence, cultural, social and psychological differences between the populations might have led to a variation of the reported diseases, pain or risk factors [52, 53]. In addition, some populations are known to be more prone to the development of MSDs. For example, the highest reported OR was 5.2 in crude and adjusted analysis [43]. The authors of this study observed young baseball players, who usually are a vulnerable group for MSDs in the upper limbs [54, 55]. Consequently, just playing baseball can be associated with MSD occurrence. On the other hand, if baseball is the physical activity of choice this could also be a protective factor, which counteracts the negative impact of video gaming. The crude and adjusted OR, which included the number of baseball practice hours among other things, did not differ from each other. Thus, the population group could have had an impact, but it seemed not to be as influential as the video game time in this study. In order to obtain more transparency and a better understanding, studies in which effects of behaviors on the musculoskeletal system are observed, should clearly show the singular impacts in complex statistical analysis. This would provide a better differentiation of the possible influencing factors.

In addition, in the present study the participants age range of the included studies ranged between 6 and 35 years. It is known that higher ages are negatively associated to health related outcomes like MSDs than younger ages [48]. Therefore, it is even more concerning that in the majority of included studies, in which young populations were observed, it was found that there is a negative association of MSDs and video game playtime. In conclusion, high video gaming times can already cause MSDs in children and adolescents. Hence, the early spread of information to parents and kids is necessary about the negative association of MSDs and excessive video game playtimes. On the other hand, specific and tailored prevention and health promotion programs for (young) video gamers are needed.

Screen-based activities and MSD

As previously mentioned, video gaming is mostly a sedentary activity and comparable with other screen-based activities like office work. Accordingly, different kind of MSDs have been associated to screen-based activities [56–58]. Therefore, several joints could be affected in different ways and with varying severities. The most affected pain regions in this review were the neck (36%), shoulder (36%) back (27%). Due to the heterogeneity in observed gaming devises and the possibility of multiple answers, no specific devise could be connected to one pain region. However, in some studies it has been shown that there is an association of specific screen-based activities with MSDs. It could be demonstrated that watching TV was associated with chronic musculoskeletal pain in Brazilian schoolteachers [59]. The authors showed that an increase in TV watch time by 30 min per day was associated with a 5.1% higher probability of having chronic musculoskeletal pain in the long-term. On the other hand, they also showed that an increase in physical activity by 60 min per week was associated with a 6.2% lower probability of chronic musculoskeletal pain. Therefore, they rated watching TV and physical activity as independent parameters, which effect MSDs in opposite ways.

Smartphone use has been associated with MSDs in the literature. In particular, upper limb [60, 61] and wrist pain [62] are common complaints. Similar results are shown in the present review. In six studies the effect of video game playtime on upper limb joints were analyzed. In four of them a significant increase was reported in OR of disorders or pain in at least one joint caused by excessive video game playing (>2-3 h/day) [33, 34, 38, 43]. These effects on the upper limbs are not surprising when the biomechanics of smartphone use is visualized, as it requires predominately upper limb activity. Additionally, excessive smartphone use (≥ 5 h/day) has been associated with lower back pain [63]. In contrast, the authors reported that all time intervals of computer use were associated with lower back pain. These results could be explained by the flexibility of smartphone usage compared with computer use. Smartphone use is independent of location and posture, can be executed along with physical activities like walking, and allows, therefore, more mobility and adaptability to delay the beginning of symptoms. In comparison, computer use is mostly a sedentary behavior, which needs a fixed place and thus limits the mobility of users.

Negative associations of neck pain in computer users have also been presented in a systematic review [58]. The relation of continuous computer use and neck pain was significant with constant mouse (> 2 h) or computer use (> 6 h). The authors also reported the associations of stressful and breakless work postures with neck pain. It can be assumed that the combination of physical inactivity, unilateral postures and repetitive movements of the upper limbs are the reasons for this. These results reinforce the findings of our review that video game playtimes of at least two to three hours a day were highly associated with MSDs.

A related analysis of 45,555 pre-adolescents showed the association of screen time in general and the degree of spinal pain [64]. It was found that the relative risk ratio in children increased with increasing hours spent in front of a screen, independent of physical activity. Consequently, screen-based activities could be considered as independent risk factors for MSD. Moreover, plenty of other health risk factors like depression in adults [65] and children [66] or obesity in childhood [67] have been linked to screen-based activities. In summary, not only video gaming, but also other screen-based activities can harm the human musculoskeletal system even if they have different requirements. In particular, continuous computer work and smartphone use were associated with MSDs and other health issues. Consequently, a combination of excessive working and leisure time screen-based activities, could lead to a highly increased risk of developing a MSD in all ages. These problems need to be counteracted at an early age.

Limitations

The results obtained in this work must be interpreted in the light of some limitations. First, the methodological quality of included studies is heterogeneous. Six out of 16 studies have a moderate to low quality, which must be recognized when interpreting any of the results. In addition, this review just included English articles, which can cause a language bias. Especially articles from countries with a big video gaming community, like China or Korea, could have been beneficial. Second, there is a lack of interventional studies in this research field, which are needed if causality is to be examined. Except for one study, the included studies had a cross-sectional design. In this design a direct causality cannot be assumed. However, if the statistics are adapted using cofactors and covariates, the principles of mediation should allow an association to be made. Third, the generic term musculoskeletal disorders includes different kinds of conditions and diseases. Consequently, there was a high heterogeneity of MSD definitions and an inconsistency of the evaluation methods of the included studies. Due to the versatility of the term MSD there was a lack of standardization of the measurement methods of MSDs. In particular, self-designed non-standardized questionnaires were mainly used for MSD evaluation. Therefore, a generalization of the results is limited because too many different non-validated measurement methods were used.

Conclusion

In eleven out of 16 studies a negative impact was demonstrated for video game playtime on the musculoskeletal system. Moreover, excessive video game playtimes (> 3 h/day) seemed to be a predictor for the appearance of MSDs. In particular, the neck, shoulder and back were the most negatively affected body regions. The combination of continuous sitting, physical inactivity and repetitive movements of the upper limbs might be the reasons for that. Additionally, other screen-based activities could even amplify this association. Due to the great popularity of video gaming across multiple generations, specific and tailored prevention and health promotion programs for video gamers need to be developed to counteract this immense public health issue. Not only casual video gamers, but also and especially esports athletes should be aware of this if they are to counteract the negative effects of long video game playtimes. For this purpose, it seems reasonable that esports professionals should serve as role models for casual video gamers. In particular, possible correlations between MSDs and different game genres should be observed. Hence, future research should be focused on prevention and health promotion programs for this target group in order to provide a basis for recommendations. Furthermore, studies are needed in which more details of the requirements and burdens are demonstrated on the human body while video gaming.

Abbreviations

GDP: Gross Domestic Product; EMG: Electromyography; MeSH: Medical Subject Headings; MSDs: Musculoskeletal Disorders; NCD: Non-Communicable Diseases; NOS: Newcastle–Ottawa Scale; OR: Odds Ratio; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCTs: Randomized Controlled Trials.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-022-05614-0.

Additional file 1. Search strategy.

Additional file 2. Adapted Newcastle-Ottawa Quality Assessment Scale.

Additional file 3. OR models of individual studies.

Acknowledgements
Not applicable.

Authors' contributions
All authors participated in the study design, have read the manuscript, and approved it. CT, PB: search strategy execution, manuscript preparation, database interpretation, statistical analysis, and manuscript revision. KW, GC: database interpretation, statistical analysis, consensus decision and manuscript revision. IF: database interpretation and manuscript revision.

Funding
Open Access funding enabled and organized by Projekt DEAL. The authors have not received any financial support for this work.

Availability of data and materials
All the data generated and analyzed during this study are included in this published article and its appendix.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors report no conflicts of interest.

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Received: 27 April 2022 Accepted: 1 July 2022
Published online: 16 July 2022

References

1. Morse KF, Fine PA, Friedlander KJ. Creativity and Leisure During COVID-19: Examining the Relationship Between Leisure Activities, Motivations, and Psychological Well-Being. Front Psychol. 2021;12: 609967. https://doi.org/10.3389/fpsyg.2021.609967.
2. DFC Intelligence. Global Video Game Consumer Segmentation. 2020. https://www.dfcint.com/product/video-game-consumer-segmentation-2/.
3. Newzoo. Global Games Market Report: The VR & Metaverse Edition. 2021. https://resources.newzoo.com/hubfs/Reports/2021_Free_Global_Games_Market_Report.pdf?utm_campaign=GGMR%202021&utm_medium=email&_hsmi=137510824&_hsenc=p2ANqtz-9SMuJv0HTWrGscoB62ryibzF4AkNR1Mgca-naHOOz2lP1rH2vi_D3AdLX-bxYs7vm-lx8SMGdqdnLh4e6iTqxoeuTu-w&utm_content=137510824&utm_source=hs_automation.
4. IHRSA. The 2020 IHRSA Global Report: The State of the Health Club Industry. 2020. https://www.ihrsa.org/publications/the-2020-ihrsa-global-report/#.
5. Unity. Covid-19's impact on the gaming industry: 19 takeaways: An examination of pandemic gaming behavior and game montization. 2020. https://images.response.unity3d.com/Web/Unity/%7B1d8bb073-24ca-45ae-9b26-4ec9ac2e3fb4%7D_Unity-Monetization-Covid-19-Insights-v3.7.pdf?elqTrackId=0cf1b3ba3dd04d708e2731e75ddaa324&elqaid=2721&elqat=2.
6. López-Cabarcos MÁ, Ribeiro-Soriano D, Piñeiro-Chousa J. All that glitters is not gold. The rise of gaming in the COVID-19 pandemic. J Innovation Knowledge. 2020;5:289–96. https://doi.org/10.1016/j.jik.2020.10.004.
7. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. Int J Behav Nutr Phys Act. 2017;14:75. https://doi.org/10.1186/s12966-017-0525-8.
8. de Rezende LFM, Rodrigues Lopes M, Rey-López JP, Matsudo VKR, Luiz OdC. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS One. 2014;9:e105620. https://doi.org/10.1371/journal.pone.0105620.
9. Park JH, Moon JH, Kim HJ, Kong MH, Oh YH. Sedentary Lifestyle: Overview of Updated Evidence of Potential Health Risks. Korean J Fam Med. 2020;41:365–73. https://doi.org/10.4082/kjfm.20.0165.
10. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388:1302–10. https://doi.org/10.1016/S0140-6736(16)30370-1.
11. Hodgetts CJ, Leboeuf-Yde C, Beynon A, Walker BF. Shoulder pain prevalence by age and within occupational groups: a systematic review. Arch Physiother. 2021;11:24. https://doi.org/10.1186/s40945-021-00119-w.
12. Gawke JC, Gorgievski MJ, van der Linden D. Office work and complaints of the arms, neck and shoulders: the role of job characteristics, muscular tension and need for recovery. J Occup Health. 2012;54:323–30. https://doi.org/10.1539/joh.11-0152-oa.
13. Jenny SE, Manning RD, Keiper MC, Olrich TW. Virtual(ly) Athletes: Where eSports Fit Within the Definition of "Sport." Quest. 2017;69:1–18. https://doi.org/10.1080/00336297.2016.1144517.
14. Borecki L, Tolstych K, Pokorski M. Computer games and fine motor skills. Adv Exp Med Biol. 2013;755:343–8. https://doi.org/10.1007/978-94-007-4546-9_43.
15. Zwibel H, DiFrancisco-Donoghue J, DeFeo A, Yao S. An Osteopathic Physician's Approach to the Esports Athlete. J Am Osteopath Assoc. 2019;119:756–62. https://doi.org/10.7556/jaoa.2019.125.
16. Funk DC, Pizzo AD, Baker BJ. eSport management: Embracing eSport education and research opportunities. Sport Manage Rev. 2018;21:7–13. https://doi.org/10.1016/j.smr.2017.07.008.
17. Jalink MB, Heineman E, Pierie J-PEN, ten Cate Hoedemaker, Henk O. Nintendo related injuries and other problems: review. BMJ. 2014;349:g7267. https://doi.org/10.1136/bmj.g7267.
18. Toosi KK, Hogaboom NS, Oyster ML, Boninger ML. Computer keyboarding biomechanics and acute changes in median nerve indicative of carpal tunnel syndrome. Clin Biomech (Bristol, Avon). 2015;30:546–50. https://doi.org/10.1016/j.clinbiomech.2015.04.008.
19. Roquelaure Y. Musculoskeletal Disorders and Psychosocial Factors at Work. SSRN Journal. 2018. https://doi.org/10.2139/ssrn.3316143.
20. Kok J de, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K, et al. Work-related musculoskeletal disorders: Prevalence, costs and demographics in the EU. 2019. https://osha.europa.eu/en/publications/work-related-musculoskeletal-disorders-prevalence-costs-and-demographics-eu/view. Accessed 20 Jan 2022.
21. National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Health Care Services; Committee on Identifying Disabling Medical Conditions Likely to Improve with Treatment. Selected health conditions and likelihood of improvement with treatment. Washington (DC): National Academies Press (US); 2020. https://doi.org/10.17226/25662.
22. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, Jørgensen K. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon. 1987;18:233–7. https://doi.org/10.1016/0003-6870(87)90010-x.
23. Finkelstein H. Stenosing tendovaginitis at the radial styloid process. J Bone Joint Surg. 1930;12:509–40.

24. Schmidt K, Friedrichs P, Cornelsen HC, Schmidt P, Tischer T. Musculoskeletal disorders among children and young people: prevalence, risk factors, preventive measures. 2021. https://healthy-workplaces.eu/en/publications/musculoskeletal-disorders-among-children-and-young-people-prevalence-risk-factors-preventive-measures.
25. Lindberg L, Nielsen SB, Damgaard M, Sloth OR, Rathleff MS, Straszek CL. Musculoskeletal pain is common in competitive gaming: a cross-sectional study among Danish esports athletes. BMJ Open Sport Exerc Med. 2020. https://doi.org/10.1136/bmjsem-2020-000799.
26. Wang D, Tang L, Wu H, Gu D. Analysis of the effect of overusing thumbs on smartphone games. J Int Med Res. 2019;47:6244–53. https://doi.org/10.1177/0300060519881016.
27. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372: n71. https://doi.org/10.1136/bmj.n71.
28. Swiss Academic Software GmbH. Citavi (6); 2020. https://www.citavi.com.
29. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5:210. https://doi.org/10.1186/s13643-016-0384-4.
30. Wells GA, Wells G, Shea B, Shea B, O'Connell D, Peterson J, WelchLosos M, Tugwell P, Ga SW, Zello GA, Petersen JA. The newcastle-ottawa scale (nos) for assessing the quality of nonrandomised studies in meta-analyses. 2014.
31. Modesti PA, Reboldi G, Cappuccio FP, Agyemang C, Remuzzi G, Rapi S, et al. Panethnic Differences in Blood Pressure in Europe: A Systematic Review and Meta-Analysis. PLoS ONE. 2016;11:e0147601. https://doi.org/10.1371/journal.pone.0147601.
32. Centre for Reviews and Dissemination. CRD's guidance for undertaking reviews in healthcare. 3rd ed. York: York Publ. Services; 2009.
33. Kang J-W, Kim H, Cho S-H, Lee M-K, Kim Y-D, Nan H-M, Lee C-H. The association of subjective stress, urinary catecholamine concentrations and PC game room use and musculoskeletal disorders of the upper limbs in young male Koreans. J Korean Med Sci. 2003;18:419–24. https://doi.org/10.3346/jkms.2003.18.3.419.
34. Ma T, Song L, Ning S, Wang H, Zhang G, Wu Z. Relationship between the incidence of de Quervain's disease among teenagers and mobile gaming. Int Orthop. 2019;43:2587–92. https://doi.org/10.1007/s00264-019-04389-9.
35. Meziat-Filho N, Azevedo e Silva G, Coutinho ES, Mendonca R, Santos V. Association between home posture habits and neck pain in High School adolescents. J Back and Musculoskeletal Rehabilitation. 2017;30:467–75. https://doi.org/10.3233/bmr-150339.
36. Tazawa Y, Okada K. Physical signs associated with excessive television-game playing and sleep deprivation. Pediatr Int. 2001;43:647–50. https://doi.org/10.1046/j.1442-200x.2001.01466.x.
37. DiFrancisco-Donoghue J, Balentine J, Schmidt G, Zwibel H. Managing the health of the eSport athlete: an integrated health management model. BMJ Open Sport Exerc Med. 2019;5:e000467–e000467. https://doi.org/10.1136/bmjsem-2018-000467.
38. Hakala PT, Rimpelä AH, Saarni LA, Salminen JJ. Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. Eur J Public Health. 2006;16:536–41. https://doi.org/10.1093/eurpub/ckl025.
39. Hellström C, Nilsson KW, Leppert J, Åslund C. Effects of adolescent online gaming time and motives on depressive, musculoskeletal, and psychosomatic symptoms. Ups J Med Sci. 2015;120:263–75. https://doi.org/10.3109/03009734.2015.1049724.
40. Torsheim T, Eriksson L, Schnohr CW, Hansen F, Bjarnason T, Välimaa R. Screen-based activities and physical complaints among adolescents from the Nordic countries. BMC Public Health. 2010;10:324. https://doi.org/10.1186/1471-2458-10-324.
41. Burke A, Peper E. Cumulative trauma disorder risk for children using computer products: Results of a pilot investigation with a student convenience sample. Public Health Rep. 2002;117:350–7. https://doi.org/10.1016/s0033-3549(04)50171-1.
42. Sekiguchi T, Hagiwara Y, Momma H, Tsuchiya M, Kuroki K, Kanazawa K, et al. Excessive game playing is associated with musculoskeletal pain among youth athletes: a cross-sectional study in Miyagi prefecture. J Sports Sci. 2018;36:1801–7. https://doi.org/10.1080/02640414.2017.1420453.
43. Sekiguchi T, Hagiwara Y, Yabe Y, Tsuchiya M, Itaya N, Yoshida S, et al. Playing video games for more than 3 hours a day is associated with shoulder and elbow pain in elite young male baseball players. J Shoulder Elbow Surg. 2018;27:1629–35. https://doi.org/10.1016/j.jse.2018.06.005.
44. Silva GR, Rodarti Pitangui AC, Andrade Xavier MK, Valois Correia-Junior MA, de Araujo RC. Prevalence of musculoskeletal pain in adolescents and association with computer and videogame use. J Pediatr (Rio J). 2016;92:188–96. https://doi.org/10.1016/j.jped.2015.06.006.
45. Yabe Y, Hagiwara Y, Sekiguchi T, Momma H, Tsuchiya M, Kuroki K, et al. Late bedtimes, short sleeping time, and longtime video-game playing are associated with low back pain in school-aged athletes. Eur Spine J. 2018;27:1112–8. https://doi.org/10.1007/s00586-017-5177-5.
46. Xavier MKA, RodartiPitangui AC, ReisSilva GR, de Oliveira VMA, Beltrao NB, de Araujo RC. Prevalence of headache in adolescents and association with use of computer and videogames. Cien Saude Colet. 2015;20:3477–86. https://doi.org/10.1590/1413-812320152011.19272014.
47. Reiner M, Niermann C, Jekauc D, Woll A. Long-term health benefits of physical activity–a systematic review of longitudinal studies. BMC Public Health. 2013;13:813. https://doi.org/10.1186/1471-2458-13-813.
48. Okunribido OO, Wynn T, Lewis D. Are older workers at greater risk of musculoskeletal disorders in the workplace than young workers? – A literature review. OER. 2011;10:53–68. https://doi.org/10.3233/OER-2011-0192.
49. Mansi S, Milosavljevic S, Baxter GD, Tumilty S, Hendrick P. A systematic review of studies using pedometers as an intervention for musculoskeletal diseases. BMC Musculoskelet Disord. 2014;15:231. https://doi.org/10.1186/1471-2474-15-231.
50. Tersa-Miralles C, Bravo C, Bellon F, Pastells-Peiró R, Rubinat Arnaldo E, Rubí-Carnacea F. Effectiveness of workplace exercise interventions in the treatment of musculoskeletal disorders in office workers: a systematic review. BMJ Open. 2022;12:e054288. https://doi.org/10.1136/bmjopen-2021-054288.
51. Sharan D, Mohandoss M, Ranganathan R, Jose J. Musculoskeletal disorders of the upper extremities due to extensive usage of hand held devices. Ann Occup Environ Med. 2014;26:22. https://doi.org/10.1186/s40557-014-0022-3.
52. Coggon D, Ntani G, Palmer KT, Felli VE, Harari R, Barrero LH, et al. Disabling musculoskeletal pain in working populations: is it the job, the person, or the culture? Pain. 2013;154:856–63. https://doi.org/10.1016/j.pain.2013.02.008.
53. Murray CJL, Aravkin AY, Zheng P, Abbafati C, Abbas KM, Abbasi-Kangevari M, et al. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. 2020;396:1223–49. https://doi.org/10.1016/S0140-6736(20)30752-2.
54. Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. Med Sci Sports Exerc. 2001;33:1803–10. https://doi.org/10.1097/00005768-200111000-00002.
55. Matsuura T, Suzue N, Iwame T, Arisawa K, Fukuta S, Sairyo K. Epidemiology of shoulder and elbow pain in youth baseball players. Phys Sportsmed. 2016;44:97–100. https://doi.org/10.1080/00913847.2016.1149422.
56. Waongenngarm P, van der Beek AJ, Akkarakittichoke N, Janwantanakul P. Perceived musculoskeletal discomfort and its association with postural shifts during 4-h prolonged sitting in office workers. Appl Ergon. 2020;89:103225. https://doi.org/10.1016/j.apergo.2020.103225.
57. Feng B, Chen K, Zhu X, Ip W-Y, Andersen LL, Page P, Wang Y. Prevalence and risk factors of self-reported wrist and hand symptoms and clinically confirmed carpal tunnel syndrome among office workers in China: a cross-sectional study. BMC Public Health. 2021;21:57. https://doi.org/10.1186/s12889-020-10137-1.
58. Keown GA, Tuchin PA. Workplace Factors Associated With Neck Pain Experienced by Computer Users: A Systematic Review. J Manipulative Physiol Ther. 2018;41:508–29. https://doi.org/10.1016/j.jmpt.2018.01.005.
59. Da Santos MCS, Gabani FL, Dias DF, de Andrade SM, González AD, Loch MR, Mesas AE. Longitudinal associations of changes in physical activity and TV viewing with chronic musculoskeletal pain in Brazilian schoolteachers. PLoS ONE. 2020;15:e0234609. https://doi.org/10.1371/journal.pone.0234609#sec002.

60. Almomani F, Alghwiri AA, Alghadir AH, Al-Momani A, Iqbal A. Prevalence of upper limb pain and disability and its correlates with demographic and personal factors. J Pain Res. 2019;12:2691–700. https://doi.org/10.2147/JPR.S198480.
61. Alsalameh AM, Harisi MJ, Alduayji MA, Almutham AA, Mahmood FM. Evaluating the relationship between smartphone addiction/overuse and musculoskeletal pain among medical students at Qassim University. J Family Med Prim Care. 2019;8:2953–9. https://doi.org/10.4103/jfmpc.jfmpc_665_19.
62. Amjad F, Farooq MN, Batool R, Irshad A. Frequency of wrist pain and its associated risk factors in students using mobile phones. Pak J Med Sci. 2020;36:746–9. https://doi.org/10.12669/pjms.36.4.1797.
63. Silva AG, Sa-Couto P, Queirós A, Neto M, Rocha NP. Pain, pain intensity and pain disability in high school students are differently associated with physical activity, screening hours and sleep. BMC Musculoskelet Disord. 2017;18:194. https://doi.org/10.1186/s12891-017-1557-6.
64. Joergensen AC, Strandberg-Larsen K, Andersen PK, Hestbaek L, Andersen AM-N. Spinal pain in pre-adolescence and the relation with screen time and physical activity behavior. BMC Musculoskelet Disord. 2021;22:393. https://doi.org/10.1186/s12891-021-04263-z.
65. Wang X, Li Y, Fan H. The associations between screen time-based sedentary behavior and depression: a systematic review and meta-analysis. BMC Public Health. 2019;19:1524. https://doi.org/10.1186/s12889-019-7904-9.
66. Liu M, Wu L, Yao S. Dose-response association of screen time-based sedentary behaviour in children and adolescents and depression: a meta-analysis of observational studies. Br J Sports Med. 2016;50:1252–8. https://doi.org/10.1136/bjsports-2015-095084.
67. Fang K, Mu M, Liu K, He Y. Screen time and childhood overweight/obesity: A systematic review and meta-analysis. Child Care Health Dev. 2019;45:744–53. https://doi.org/10.1111/cch.12701.

Publisher's Note

C. Studie II: How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming

frontiers | Frontiers in Sports and Active Living

TYPE Original Research
PUBLISHED 10 July 2024
DOI 10.3389/fspor.2024.1370485

OPEN ACCESS

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RECEIVED 14 January 2024
ACCEPTED 20 June 2024
PUBLISHED 10 July 2024

CITATION
Tholl C, Soffner M and Froböse I (2024) How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming.
Front. Sports Act. Living 6:1370485.
doi: 10.3389/fspor.2024.1370485

How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming

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Introduction: Esports or competitive video gaming is a rapidly growing sector and an integral part of today's (youth) culture. Esports athletes are exposed to a variety of burdens, that can potentially impact an athlete's health and performance. Therefore, it is important that esports athletes are aware of (physical) burden and exertion associated with esports. For this purpose, a study was conducted to evaluate the influence of competitive video gaming on the perceived physical exertion and the perceived physical state (PEPS).

Methods: Thirty-two healthy male esports athletes participated in two competitive video gaming sessions lasting 90–120 min, interrupted by a 10-minute passive sitting break. Repeated measures of perceived physical exertion (Borg Categorial Ratio-10 scale) and perceived physical state were recorded before, during, and after each video game session. Repeated measures ANOVA and Friedman's test were used for statistical analysis.

Results: The results showed a significant difference in all dimensions of the PEPS ($p < 0.05$) as well as in Borg scale ($p < 0.001$). Post-hoc tests revealed significant increases in Borg scale between baseline measurements (T0: 1.0 ± 1.0) and after the first competitive video gaming session (T1: 2.4 ± 1.3, $p < 0.001$), as well as after the second competitive video gaming session (T3: 3.0 ± 1.7, $p < 0.001$). Furthermore, there was a significant reduction in perceived exertion between the measurement time after the first competitive video gaming session (T1) and the break (T2: 1.3 ± 1.2, $p < 0.001$). The PEPS dimensions activation, trained, and mobility showed similar significant changes in post-hoc analysis.

Discussion: The results indicate that the perceived physical burden significantly increases during esports participation. As the duration of competitive video gaming extends, the perceived physical state decreases and perceived physical exertion increases. A passive break between two video game sessions can at least partially restore physical exertion and physical state. However, this break neither returns the scores to their baseline levels nor prevents a further decline in scores during the second video game session. Over time and with a lack of observation, this could result in health and performance limitations.

KEYWORDS
video games, RPE, sedentary behavior, ANOVA, fatigue, rest

1 Introduction

The video gaming sector has been a rapidly growing area for several years. This has led to a massive increase in video game players, spectators, and the global video game market over the past decade (1). It is estimated that there were 3.4 billion video game players globally in 2023 (1). One part of the video gaming sector is electronic sports (esports), also known as competitive video gaming (2). In esports, athletes compete against each other in different virtual environments. Today, esports athletes compete in tournaments with millions of dollars in prize money, attract millions of viewers and serve as role models, especially for young people (3, 4). Therefore, it is not a short-term trend, but an integral part of today's (youth) culture and competitive sports industry.

With the growing interest in esports, the performance and health of esports athletes has become a focus for organizations and researchers. Esports athletes train between 4 and 10 h/day to develop (game-)specific abilities depending on their skill level and the game genre (5, 6). The requirements range from mechanical skills to control the digital environment, to tactical-cognitive skills to plan moves or cooperate with teammates, to psychological skills such as resilience (7). Currently, there is a lack of evidence in which esports games players spend the most time playing, or which skills require the most training to develop. In addition, esports athletes are exposed to a variety of burdens, that can affect an athlete's health and/or performance (8, 9). Various biopsychosocial stressors such as prolonged sitting (10), high mental stress, or team issues are present in esports (11). A recent systematic review on stress in esports revealed different psychophysiological responses (12). Interestingly, the participation in non-competitive esports games does not seem to be associated with changes. In competitive settings however, mixed results have been found, indicating potential changes in the heart rate, heart rate variability, and blood pressure (12). Research has shown that esports athletes' perceptions of psychological stress can be influenced by winning or losing their games (13).

In addition to these psychophysiological responses, the physical burdens of esports and its potential consequences have previously been discussed (14). Video gaming and esports by their (current) nature are mostly sedentary behaviors combined physical inactivity (15), monotonous and prolonged sitting (8), and repetitive movements of the upper extremities (16). Except for exercise or virtual reality games, which require physical movements to interact with the digital environment and could increase physical activity (17). As a result, excessive video gaming may lead to the occurrence of musculoskeletal disorders (14). Consequently, not only could the health of esports athletes be compromised, but their performance may also be affected due to impairments. Such physical ailments could lead to early retirement (9). Therefore, it is important that esports athletes are aware of physical burden and exertion in order to counteract these consequences. This requires good self- and body perception. However, there is a lack of evidence on body perception during competitive video gaming. As mentioned above, perceived physical exertion is of particular interest in terms of injury prevention and intensity control. The findings could be useful for load management, intensity control and self-perception in esports.

Therefore, the overall aim of this study is to examine the perceived physical burdens of esports athletes during competitive video gaming. We hypothesized that the perceived physical exertion would increase and the perceived physical state would decrease over time.

2 Materials and methods

2.1 Study design

This study used a repeated measures, within-group, non-randomized design. Due to the exploratory approach and the non-standardizable nature of the video game activity the study focused on within-group study design. This allows the participants to act as their own control, reducing individual variability for between-group comparisons. The study took place in the laboratory of the Institute of Movement Therapy and Movement-oriented Prevention and Rehabilitation at the German Sport University Cologne. Between 06/2023 and 12/2023 esports athletes were recruited for a five-to-six-hour investigation. The participants took part in two competitive video gaming sessions of 90–120 min interrupted by a 10-minute passive sitting break (Figure 1). At the measurement points (T0-T3) and during video game play, objective and subjective parameters were examined. The study protocol followed the ethical principles defined in the declaration of Helsinki and were approved by the ethical committee of the German Sport University Cologne (reference: 093/2023).

2.2 Participants

Thirty-two healthy male esports athletes from Germany met the following inclusion criteria: (1) esports athlete defined by being in the top 20% of the in-game ranking system, (2) playing computer-based multiplayer online battle arena (MOBA) or first-person shooter (FPS) games, (3) mouse and keyboard usage, (4) mouse operation with the right hand, (5) using a mouse sensitivity between 400 and 3,000 dots per inch (dpi), (6) aged between 18

FIGURE 1
Study design.

and 35 years. The age range reflects the majority of esports athletes (5, 10, 18). Participants were excluded if they reported (1) acute or chronic upper body musculoskeletal disorders, (2) uncorrected visual impairment, (3) severe migraine or epilepsy, (4) medication-induced vigilance or vision impairment, or (5) severe physical or cognitive stress on the previous day. Participants were recruited via social media (*Discord, Instagram, LinkedIn*), in person at video game venues or at various universities in Cologne Germany, as well as through esports organizations. Participant recruitment was open to all genders.

2.3 Procedure

The study was conducted by trained and experienced instructors and included subjective and objective parameters. This article will focus on the subjective parameters and procedures. The biomechanical analysis is only partially mentioned to understand the structure of the entire study protocol and will be part of another article. Participants were asked to avoid cognitively or physically demanding activities on the day before and on the day of the test. They were also asked to abstain from alcohol for 12 h, from caffeinated beverages for five hours, and not to use any lotions/creams on the day of the test. At the beginning of the examination, participants were informed about the study protocol and signed the informed consent form. Inclusion and exclusion criteria were then checked, and anthropometric data were recorded. In addition to body weight and height, circumferences, and dimensions of the upper body were collected without clothing. Subsequent recoding of electromyographic, electrocardiographic and motion capture data was prepared. After the preparation for the biomechanical analysis, participants were asked to complete a partially standardized online questionnaire at the testing station.

The standardized test station consisted of an adjustable chair with demounted armrest for a better hip motion capture, an adjustable desk, and ten motion capture cameras. While the participants answered the questionnaire, the instructors checked the objective data for plausibility. After completing the questionnaire, participants were allowed to warm up and adjust their settings in the video game for ten minutes. The video game played could be chosen by the participant. The esports title had to be a MOBA (League of Legends, Defense of the Ancients 2) or FPS (Counter-Strike, Valorant, Overwatch, Rainbow Six Siege) video game. Immediately prior to the start of the measurement, participants were asked to do their best to win the games.

After this preparation phase (T0) and at each other measurement point (T1-T3), participants were asked to answer short questionnaires about their current perceived physical state and the current physical exertion. Measurements commenced with the first competitive video gaming session. To ensure typical stress conditions similar to the official competitions, participants had to play ranked games using their main accounts. During the competitive video gaming sessions, participants were asked to rate their perceived physical exertion every 15 min. The sessions ended within 90–120 min, depending on the time each game was finished. Typically, a single game lasted 25–45 min. Therefore, participants had to play multiple games to meet the minimum of 90 min of data collection. If a video game session lasted longer than 120 min, the data recordings for that session were stopped. The competitive video gaming sessions were interrupted by a 10-minute passive sitting break at another chair with armrests. Break duration reflects the average break between tournament games, which may vary between games and tournaments (19–21). Eating and drinking were permitted without restrictions on specific foods or caloric intake. Only caffeinated beverages and smoking were prohibited. Participants were not allowed to be physically active during the break. After the second competitive video game session, a five-minute passive sitting recovery period was part of the study. During this phase, only heart rate monitoring was continued. All other data collection was already completed (Figure 1).

2.4 Measuring instruments & outcomes

The questionnaire was designed to assess socio-demographic data, video gaming behavior, physical activity, sitting time, and prevalence of musculoskeletal disorders of esports athletes. It was administered via the online survey tool Unipark (*Questback GmbH, Cologne, Germany*). The questionnaire contained a total of 38–50 questions, depending on participants' answers to filter questions. First, demographic data such as age, gender, education, and employment status of the participants were collected. The wording and assessment of these questions were designed according to the standards of the German Federal Statistical Office (22). Since an appropriate and validated questionnaire was not available, questions about video game and esports training behaviors were self-designed.

Participants were first asked about their video game genre, their primary video game title and their in-game rank. In order to make the rank distribution of each game comparable, the percentage ranks are given and subdivided: ≤1%, ≤5%, ≤10%, ≤20%. Secondly, the video game experience in years, their mouse dpi and in-game (mouse) sensitivity were queried. Thirdly, they were asked about their video game playing time in hours per week differentiated according by mode:

- "Alone/without human players against human opponents (PvP)"
- "With human players against human opponents (Coop PvP)"
- "Alone/without human players against computer-controlled opponents (PvE)"
- "With human players against computer-controlled opponents (Coop PvE)"

The sum corresponded to the total video game playtime per week. The questionnaire also asked if the participants were a member of an esports club and participated in regular esports training. If they participated in esports training, the follow-up question about the organization of the training contained the following responses:

- "I train in a (regional) club with a coach"

- "I train in a (regional) club without a coach"
- "I train in a team with a coach"
- "I train in a team without a coach"
- "I train with friends"
- "I train alone or with random opponents/teammates"

Multiple answers were possible. In addition, esports training content was asked on a 4-point rating scale ("never", "sometimes", "frequently", "always"):

- Game mechanics
- Tactics
- Game analysis (own games)
- Game analysis (opponents and role models)
- Team building
- Communication with team members
- Reaction speed
- Targeted training of fine motor skills/precision/mechanical skills
- Dealing with stressful situations (in the game)
- Physical fitness
- Relaxation/regeneration
- Other

Participants were additionally queried regarding the proportion of their esports training conducted on PCs and the average weekly training duration in hours. The second part of the questionnaire covered health issues such as overall health, musculoskeletal disorders, physical activity and sitting time. The overall health was observed with a single question and includes the overall health status of the last 4 weeks on a 5-point rating scale: "poor", "fair", "good", "very good", "excellent".

Musculoskeletal disorders were evaluated with the validated German version of the *Nordic Musculoskeletal Questionnaire* (NMQ) (23, 24). Physical activity was assessed with the *European Health Interview Survey—Physical Activity Questionnaire* (EHIS-PAQ) (25). The *Sedentary Behavior Questionnaire* (SBQ) was used to assess weekday and weekend seating times (26). The EHIS-PAQ and SBQ were also available in a validated German version.

In addition to this baseline questionnaire, a modified version of the *Borg Categorial-Ratio-10 scale* (CR10) was used to assess only the physical exertion at the measurement points (T0-T3) and every 15-minutes in the competitive video gaming sessions (27). The scale rated the perceived physical exertion from 0 "No physical exertion" to 10 "Extremely strong physical exertion" (Supplementary Material Figure S1). In addition, a German validated list of adjectives was used to assess participants' current perceived physical state (PEPS) (28). The PEPS is recommended for monitoring changes in perceived physical state during exercise classes to detect short-term changes and was used at measurement points. The assessment is based on a six-point rating scale. Only the endpoints of the scale are verbally anchored (0 = "not at all"; 5 = "completely"). A self-translated English version can be found in the Supplementary Materials.

2.5 Sample size

An *a priori* power analysis was performed using *G*Power* software (version 3.1.9.7) to estimate the sample size required for repeated measures of variance (one-way ANOVA) (29). Due to a lack of scientific evidence, we assumed a mean effect size (f) of 0.25, a significance level (α) of 0.05, and a power (1-β) of 0.8. The analysis included 2 groups (within factors), 4 measurements (T0-T3), a correlation between repeated measures set at 0.5, and a non-sphericity correction (e) of 1. The results indicated a required sample size of $N = 24$.

2.6 Statistical methods

All statistical analysis were performed using *R* software (version 4.3.1) (30). Data was checked for completeness, plausibility and outliers. Participants were contacted if plausibility was questionable (e.g., reported >6 h/day of exercise). Outliers were excluded if they were greater or less than three times the standard deviation (31). Descriptive statistics are presented as the mean ± standard deviation (SD).

After this the prerequisites for a repeated measures ANOVA were examined. Normal distribution was visually analyzed at each measurement point for each variable using quantile-quantile (QQ) plots. Normal distribution was assumed if data appears as roughly a straight line. QQ plots for each variable are included in the supplementary (Supplementary Material Figures S2–S7). Sphericity was tested with *Mauchly's test*. If the assumption was violated ($p \leq 0.5$), the *Greenhouse-Geisser* correction was used. Changes over time were tested by repeated measures ANOVA with *Bonferroni* post-hoc analysis. Effect sizes were calculated by using *Cohen's d* and interpreted as small = 0.2, moderate = 0.5 and large = 0.8 effect (32). The *Friedman* test was used for non-normally distributed data. Multiple pairwise comparisons were estimated using the all-pairs test with exact *p*-values and *Bonferroni* adjustment (33). Effect sizes for Friedmann are calculated only for the overall effect with *Kendall's W*. The coefficient ranges from 0 = indicating no relationship, to 1 = indicating a perfect relationship (34). The significance level for all analyses was set at $p < 0.05$. In line with the open science principle, all data as well as the R-syntax will be available one year after publication and can be found in the supplementary.

3 Results

3.1 Participants

Table 1 displays the sample characteristics. In total, 32 male participants, with an average age of 23.8 years (± 3.4), were included in the study without any dropouts. Sociodemographic data revealed that 85% of participants held at least an A-level degree (higher education entrance qualification) and 69% were currently college students. Average physical activity level was

TABLE 1 Sample characteristics.

Variables	N	Percent	Mean	SD
Anthropometric	32			
Age [years]			23.8	3.4
Height [cm]			180.2	6.7
Weight [kg]			80.8	13.9
Body-mass-index [kg/m^2]			24.8	3.7
Physical behavior	32			
Physical activity [min/week]			307.8	327.9
Sedentary time workdays [h/day]			8.4	3.4
Sedentary time weekends [h/day]			10.1	3.3
Video game behavior	32			
Video game playtime [h/day]			3.6	1.95
Video game experience [years]			12.6	4.26
Video game genre	32			
MOBA	22	69		
FPS	10	31		
In-game rank distribution	32			
1%	9	28		
5%	10	31		
10%	6	19		
20%	7	22		
Highest degree	32			
Secondary school	1	3		
High school	1	3		
Technical college entry	3	9		
A level	22	69		
University degree	5	16		
Occupation	32			
School student	1	3		
College student	22	69		
Full-time employed	2	6		
Part-time employed	4	12		
Marginal employed	1	3		
Vocational training	1	3		
Unemployed	1	3		

307.8 min/week (± 3.4) and mean sedentary time on workdays was 8.4 h/day (± 3.4). On average, participants spent 3.6 h/day (± 2.0) playing video games, with MOBA being the dominant genre among them with 69%. Every participant achieved a ranking within the top 20% of their respective in-game ranking systems. Additionally, 59% achieved rankings in the top 5% or higher.

The musculoskeletal complaints with all temporal prevalences can be found in Table 2. With regard to the one-year prevalence of musculoskeletal complaints, neck discomfort was the most common complaint among the participants (Table 2). Hand and wrist discomfort were the most common complaints for both four-week and seven-day prevalence.

Figure 2 shows the exact training content. Only 15 out of 32 esports athletes participate in regular esports training. They are most likely to train either alone (53.3%), in a team (53.3%), in a team with a coach (40.0%) or with friends (40.0%). There is minimal training with an esports club (26.7%) or with a club and with a coach (6.7%).

3.2 Perceived physical state

Figures 3–6 displays the box plots of the perceived physical condition during the competitive video gaming sessions. The results of the ANOVA with repeated measures show a significant difference in all dimensions of the PEPS: activation ($p < 0.001$, $\eta^2 = 0.26$), trained ($p < 0.001$, $\eta^2 = 0.08$), health ($p = 0.014$, $\eta^2 = 0.08$) and mobility ($p < 0.001$, $\eta^2 = 0.13$). However, the post-hoc tests revealed that only T0 differs from T3 in the health dimension ($p = 0.039$). In the other three dimensions, all measurement times differ significantly from each other with exception of T0 to T2. Overall, there was a decrease over time. The activation dimension went from 4.19 ± 0.62 at T0 to 2.89 ± 1.16 at T3 (−26%). The trained dimension decreased from 3.25 ± 0.85 to 2.59 ± 0.85 (−13.2%) and mobility dimension from 3.43 ± 0.67 to 2.58 ± 0.93 (−17%). In addition, all show a moderate to large effect size. The results of all post-hoc tests are shown in in the supplementary (Supplementary Material Table S1).

3.3 Borg scale

Figure 7 shows the boxplots of the Borg scale at the four measurement points. The Friedmann test indicates significant differences between the measurement times according to the Borg scale ($p < 0.001$, $\omega = 0.66$). The post-hoc tests revealed significant differences between baseline (T0) measurements

TABLE 2 Prevalences of musculoskeletal disorders for different body parts.

Body part	One-year prevalence *n* (%)	Restricted by pain last year *n* (%)	Four-week prevalence *n* (%)	Seven-day prevalence *n* (%)
Neck	16 (50.0)	2 (6.3)	5 (15.6)	2 (6.3)
Shoulders and upper arms	7 (21.9)	3 (9.4)	3 (9.4)	2 (6.3)
Elbows and forearms	4 (12.5)	2 (6.3)	2 (6.3)	0 (0.0)
Hands and wrists	9 (28.1)	3 (9.4)	6 (18.8)	4 (12.5)
Thoracic spine	10 (31.3)	0 (0.0)	3 (9.4)	1 (3.1)
Lumbar spine	10 (31.3)	5 (15.6)	4 (12.5)	1 (3.1)
Hip joints and thighs	3 (9.4)	2 (6.3)	2 (6.3)	1 (3.1)
Knee joints	4 (12.5)	1 (3.1)	3 (9.4)	3 (9.4)
Lower leg	4 (12.5)	2 (6.3)	1 (3.1)	0 (0.0)
Feet and ankles	5 (15.6)	3 (9.4)	4 (12.5)	2 (6.3)

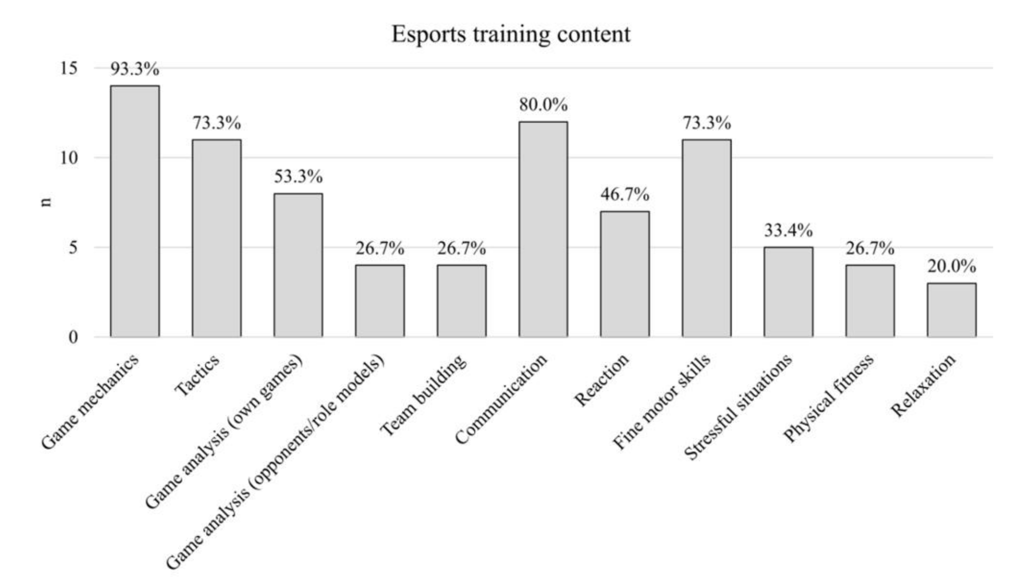

FIGURE 2
Content of esports athletes' structured trainings (n = 15). Values represented participants who stated that they frequently or always train for that aspect in their training sessions.

(1.0 ± 1.0) and after the first (T1) competitive video gaming session (2.4 ± 1.3, $p < 0.001$) as well as after the second (T3) competitive video gaming session (3 ± 1.7, $p < 0.001$). Accordingly, Borg scale increased by 2 points over the entire measurement, which corresponds to an increase of 20%. Furthermore, there was a significant difference between the measurement time after the first competitive video gaming session and the break (T2) (1.3 ± 1.2, $p < 0.001$). Lastly, there was also a significant difference between T2 and T3 ($p < 0.001$).

Considering the measurement times of the borg scale every 15 min during the competitive video gaming sessions, the results of the Friedmann test also show significant differences ($p < 0.001$, $\omega = 0.25$). Figure 8 displays the box plots of the borg scale with measurement points every 15 min during the competitive video gaming sessions. For reasons of clarity, only the most important significances are shown in the figure. The results of the post-hoc tests between all time points can be found in the supplementary (Supplementary Material Table S3).

4 Discussion

The purpose of this study was to examine the perceived physical burdens of esports athletes. Thirty-two male esports athletes participated in two 90–120-minute competitive video gaming sessions and reported their perceived physical exertion and perceived physical state. The main finding of this study is that the perceived physical burdens significantly increase during esports. As the duration of competitive video gaming extends, the perceived physical state decreased and the perceived physical exertion increased. Therefore, the hypothesis can be confirmed. However, a 10-minute passive break between competitive video gaming sessions only temporarily reduced perceived physical burdens.

4.1 Perceived physical burdens in esports

Each PEPS dimension was associated with significant decreases over time (see Figures 3–6). The largest decrease was recorded in the activation dimension (−26%) and the lowest in health (−4%). With exception of health, every dimension also indicated significant changes between measurement points. It seems logical that a complex and solid construct like health would not be affected by a temporary mental and sedentary activity like esports. In addition, the control variables "physical pain" and "physical discomfort", which are related to the health dimension (28), did not show a significant change between measurement points (Supplementary Material Table S2). A possible reason could be the short duration of video gaming (3–4 h), which might not be sufficient to develop pain or health issues. Additionally, musculoskeletal disorders are often a result of chronicity, which takes time to develop (35, 36). Therefore, playing video games repeatedly for extended periods could potentially impact physical health and the perceived physical state (14). The other PEPS dimensions exhibited similar changes

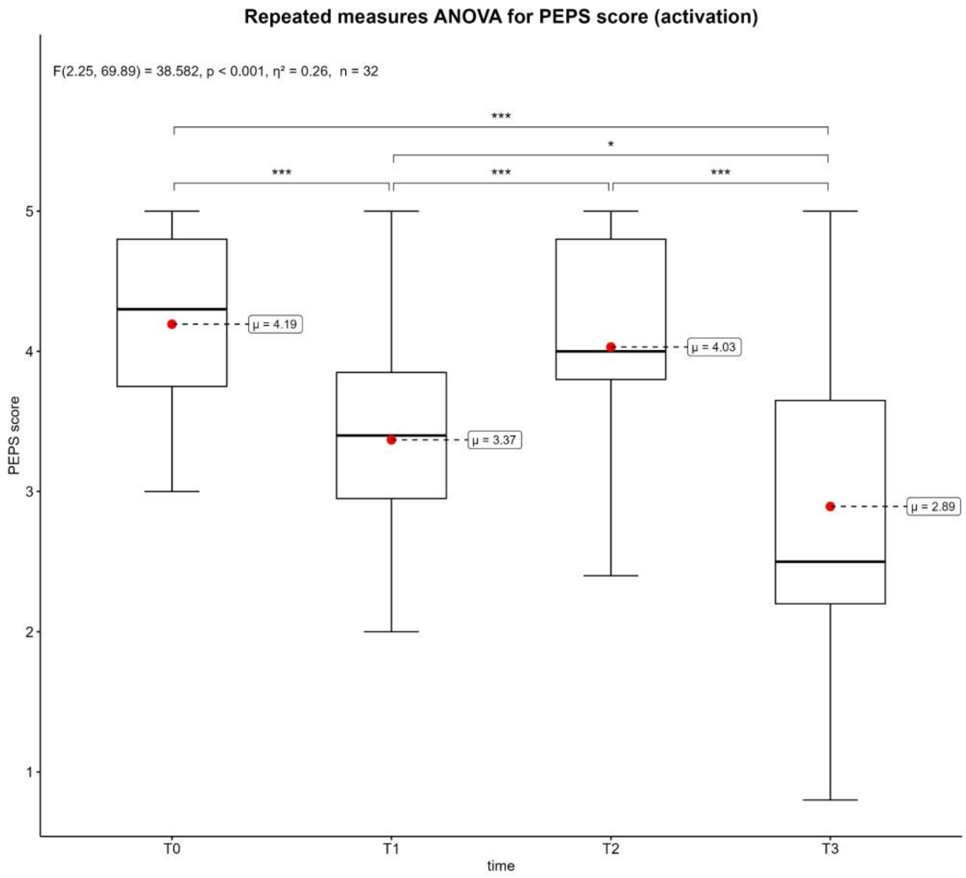

FIGURE 3
Box plots of the PEPS dimension activation across the measurement points. T0 = baseline, T1 = after the first competitive video gaming session, T2 = after the ten-minute break, T3 = after the second competitive video gaming session. *: $p \le 0.05$, **: $p \le 0.01$, ***: $p \le 0.001$ with *Greenhouse-Geisser* correction.

of the PEPS scale. A decrease after both competitive video gaming sessions and a recovery after the break, with the decrease in the second phase being greater than in the first. This could indicate that a 10-minute break between two competitive video gaming sessions could have a positive impact on perceived physical state. However, this break does not restore the PEPS scores to their baseline levels, nor does it prevent a further decline in PEPS scores during the subsequent video game session. In particular, the second session (T2-T3) showed large effect sizes in all PEPS dimensions except the health dimension (Supplementary Material Table S1). Consequently, regular breaks could have a beneficial effect on perceived physical burdens but cannot prevent esports athletes from an increase of these perceived burdens over time. The duration or type of breaks as well as the accumulation of loads could explain this. In relation to different types of breaks, similar results were shown for executive function (37). This study compared walking, sitting, supine rest and no break between 60 and 75 min of FPS gaming. The results suggest that walking and continuous play lead to significantly better executive function scores than supine rest (37). The results of a recently published review, which summarized the positive effects of active breaks in sedentary adults, are partially consistent with these findings (38). According to the authors, metabolic, cardiovascular, and cognitive improvements are associated with light to moderate physical activity or intermittent standing. At the same time, active breaks may mitigate abnormal vascular and hormonal changes which are associated with excessive sitting (38). Consequently, regular breaks could not only improve

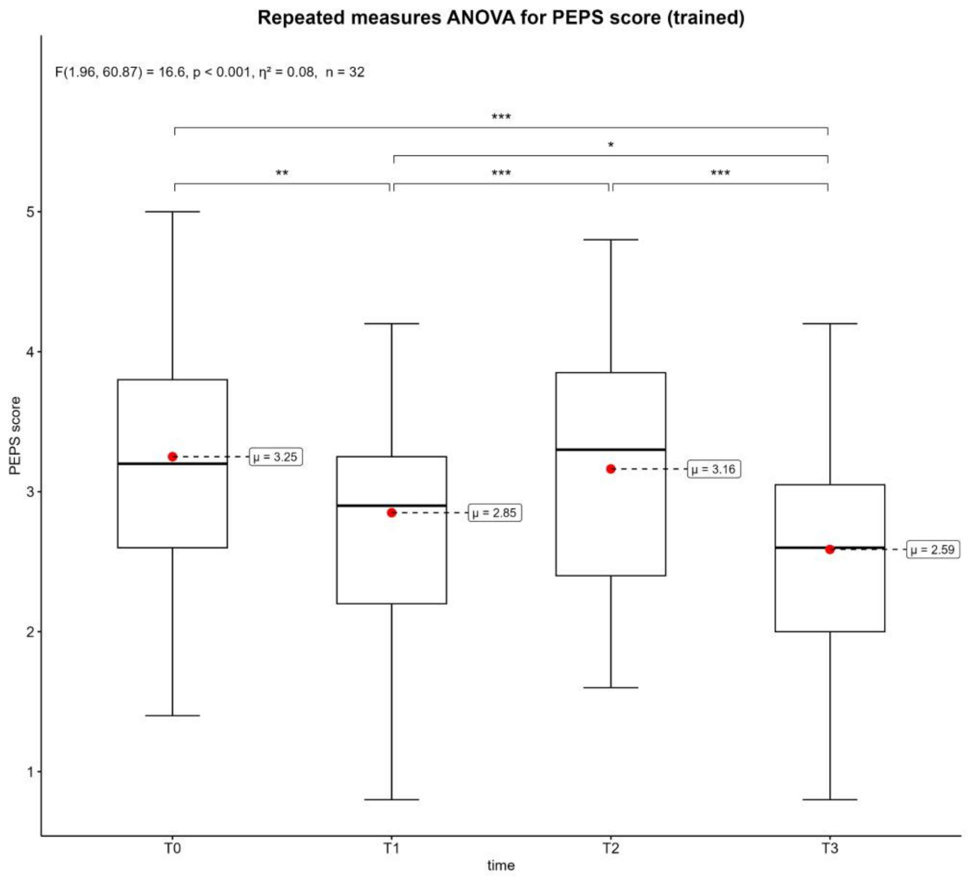

FIGURE 4
Box plots of the PEPS dimension trained across the measurement points. T0 = baseline, T1 = after the first competitive video gaming session, T2 = after the ten-minute break, T3 = after the second competitive video gaming session. *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, with *Greenhouse-Geisser* correction.

performance of esports athletes, but also benefit their health and body perception. Specifically, the implementation of active break routines should be strongly encouraged.

The distribution pattern of Borg ratings at measurement points is similar to that of the PEPS ratings. The reverse scaling should be taken into account. Therefore, the perceived physical exertion increased significantly during competitive video gaming sessions and decreased after the break (Figure 7). The overall (T0-T3) increase in mean Borg scale was from "very weak" (=1) to "moderate" (=3). More detailed insights were gathered from continuous Borg scores during competitive video gaming (Figure 8). The values fluctuate and do not form a linear increase. Unexpectedly, the highest Borg score of the first session was reached at the penultimate measurement point (T0-75). Similarly, a higher score was achieved in the second phase at T2-60 than at T2-75. The nature of competitive video gaming may be the reason. In order to compete with other esports athletes of the same skill level, competitors must join queues. Depending on their skill level and the availability of other esports athletes, the queue time can vary (39). This can result in higher scattering and different peaks of Borg scale. But even 90-minutes of competitive video gaming significantly increased the Borg scores. Thus, 3–4 h of esports noticeable increase the perceived physical exertion. In addition, a 10-minute break can provide short-term recovery from physical exertion. However, compared to esports training durations of up to 11 h/day (40) or tournament conditions it is concerning that even this shorter duration of competitive video gaming produces such significant changes. As mentioned above, loads could accumulate and lead to higher perceived exertions and burdens over time. Only one

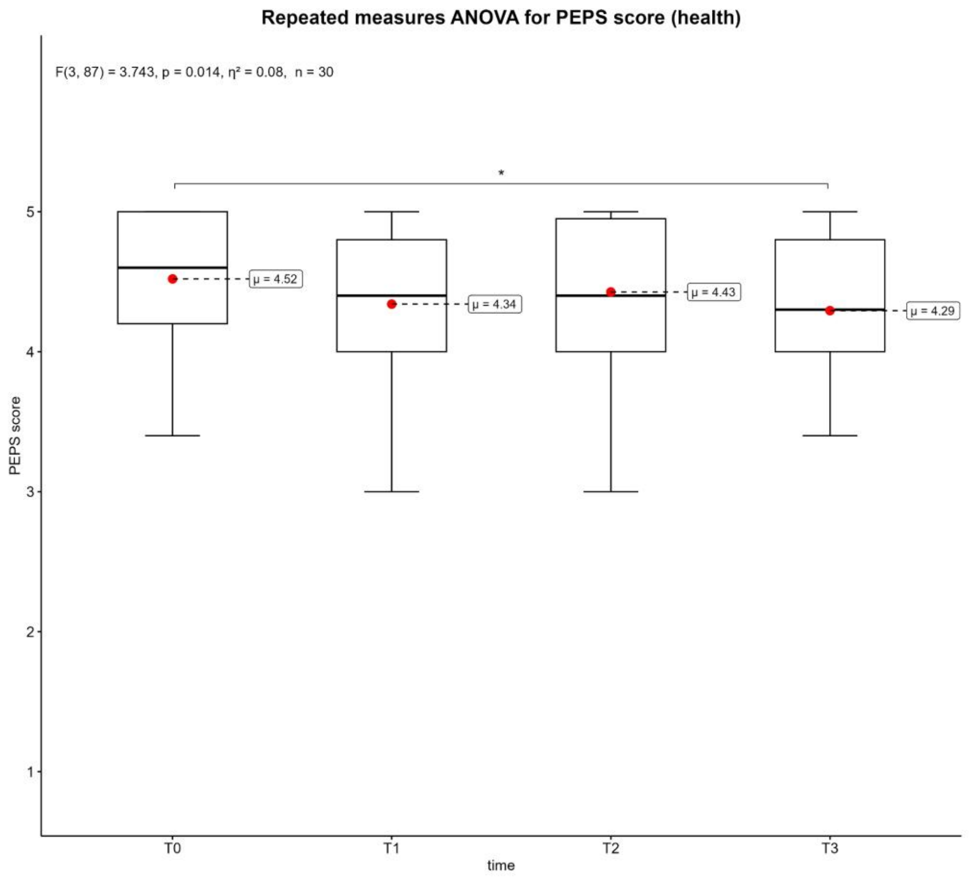

FIGURE 5
Box plots of the PEPS dimension health across the measurement points. T0 = baseline, T1 = after the first competitive video gaming session, T2 = after the ten-minute break, T3 = after the second competitive video gaming session. *: $p \le 0.05$, **: $p \le 0.01$, ***: $p \le 0.001$.

other study used Borg scale with video gamers, but only after playing (37). The study showed Borg scores on the original scale (6–20) with a mean of 11.3–13.4, indicating "fairly light" to "somewhat hard" intensities. In this case, the highest scores were reached after continuous, uninterrupted video game play, but without significant differences from the other groups (37). Thus, the ratings are similar to the Borg scale, but they differ in terms of methodology. What distinguishes the present study is the application of time series analysis to the Borg scale. However, this is an indication of the perceived burdens that playing video games places on esports athletes. Related results were found for prolonged sitting for 4 h and an increase in perceived discomfort in different body parts (41). This could be a possible reason for an increase in the Borg score, but as mentioned above, physical discomfort or pain did not increase significantly in the present study. Therefore, it can be assumed that the Borg score increased independently of discomfort or pain. In conclusion, in the current study esports athletes perceived moderate physical exertion after 3–4 h of competitive video gaming. In addition, this study shows that a passive break between two sessions can at least partially restore physical exertion and physical state. Nevertheless, future research should evaluate various types of breaks and break durations to gain a better understanding of their potential health and performance benefits. This understanding can then be used to implement breaks into esports training in a more meaningful manner.

4.2 Limitations and strengths

The results of this work should be understood in the context of certain limitations. The study was designed without a control group

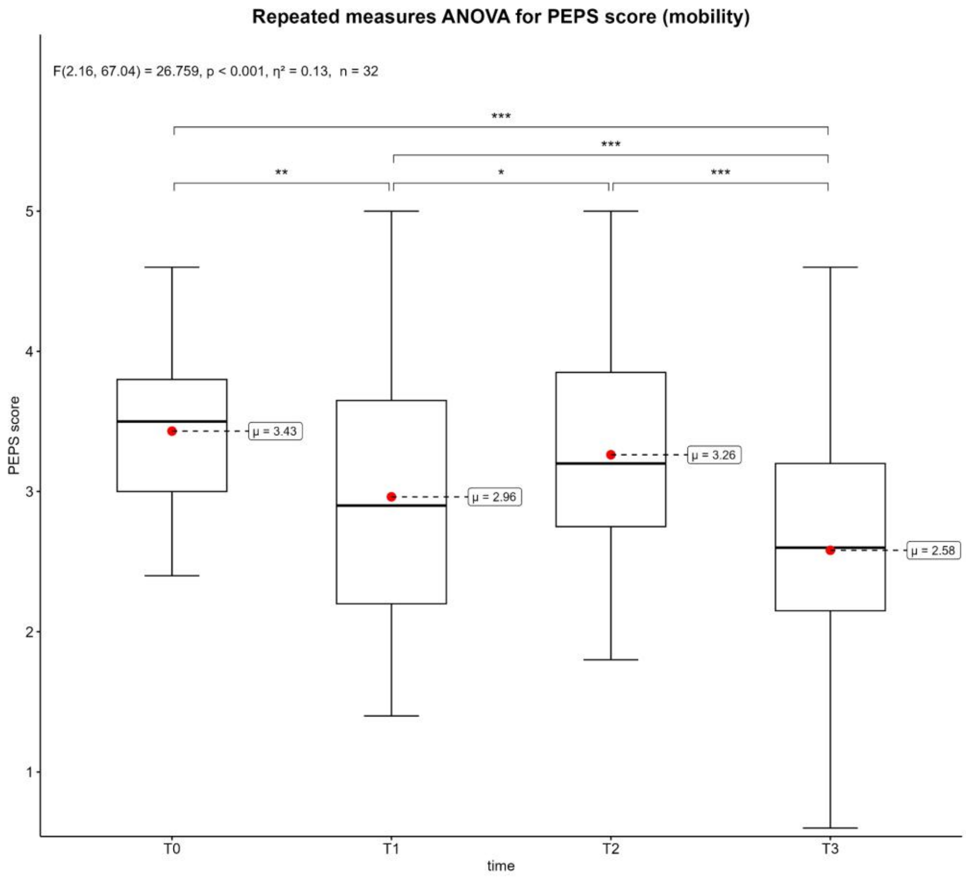

FIGURE 6
Box plots of the PEPS dimension mobility across the measurement points. T0 = baseline, T1 = after the first competitive video gaming session, T2 = after the ten-minute break, T3 = after the second competitive video gaming session. *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, with *Greenhouse-Geisser* correction.

or comparison, which limits the causality and may lead to biased results. In addition, competitive video game time ranged between 90 and 120 min per session. Therefore, some participants played longer periods of time, which can affect the results. In contrast, during these competitive video game sessions, participants had to wait in queue for their games. This queue time was not recorded but can vary from few seconds up to 10 min. This time often depends on the rank of the esports athletes and increases with rank. As result, some participants had less time to play competitively. Moreover, esports athletes out of different video game genres (MOBA, FPS) were included, due to the suspected similar exposure. Because of the sample size, the groups were not compared and the statistical models were not adjusted for this. Furthermore, no validated measuring instrument for perceived physical burdens in esports exists. Therefore, measuring instrument were used that are validated, but originally designed for physically active behavior. This can result in bias. In addition, the interpretation of the PEPS dimension activation should also be viewed critically. This dimension consists of the adjectives energy less, exhausted, drained, flabby, and limp, and could also be associated with mental processes. Mental capacity could easily be affected by mental workload, such as esports. This could lead to less differentiation between mental and physical activation after competitive video gaming sessions. In contrast, (light) physical activity results in increased scores on the activation dimension (28), which could be due to physical or psychological factors. Additionally, only male esports athletes registered for this study. Therefore, the recruitment strategy should have been modified to attempt to improve the recruitment rate of non-male esports athletes and to avoid gender bias.

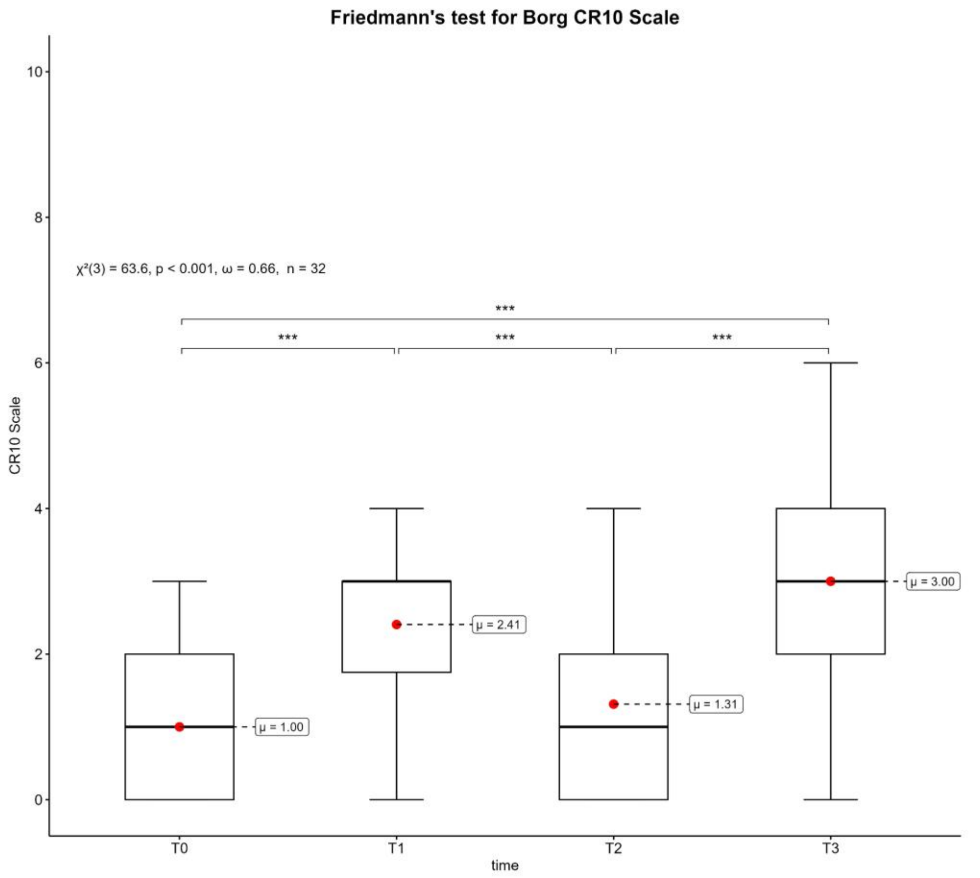

FIGURE 7
Box plots of the borg scale across the measurement points. T0 = baseline, T1 = after the first competitive video gaming session, T2 = after the ten-minute break, T3 = after the second competitive video gaming session. *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$.

However, this study showed for the first time how esports athletes perceive physical burdens under realistic conditions in a controlled setup. This will contribute to the understanding of internal and external workloads associated with esports competition and training. In addition, the data sample size is strong for interventional esports research.

4.3 Practical implications

It is important to consider these results when structuring training programs for esports athletes. Regular breaks should be included in any esports training routine to avoid an increase in perceived physical burdens. In this study, passive breaks at least partially restored physical exertion and physical state. To enhance this effect and improve health and performance, physical activity should be a part of these breaks (42, 43). Even a 6-minute walk can improve cognitive function and subjective well-being in esports athletes (37).

Furthermore, body perception and perception of exhaustion should be trained. This could potentially empower esports athletes and coaches in load management and monitoring. In particular, coaches and health professionals should implement regular monitoring of these conditions in order to adjust training and health programs. As result, performance declines and health issues could be prevented or counteracted at an early stage. Additional objective measures, such as heart rate variability, eye tracking, or electromyography, could be beneficial as comparative parameters.

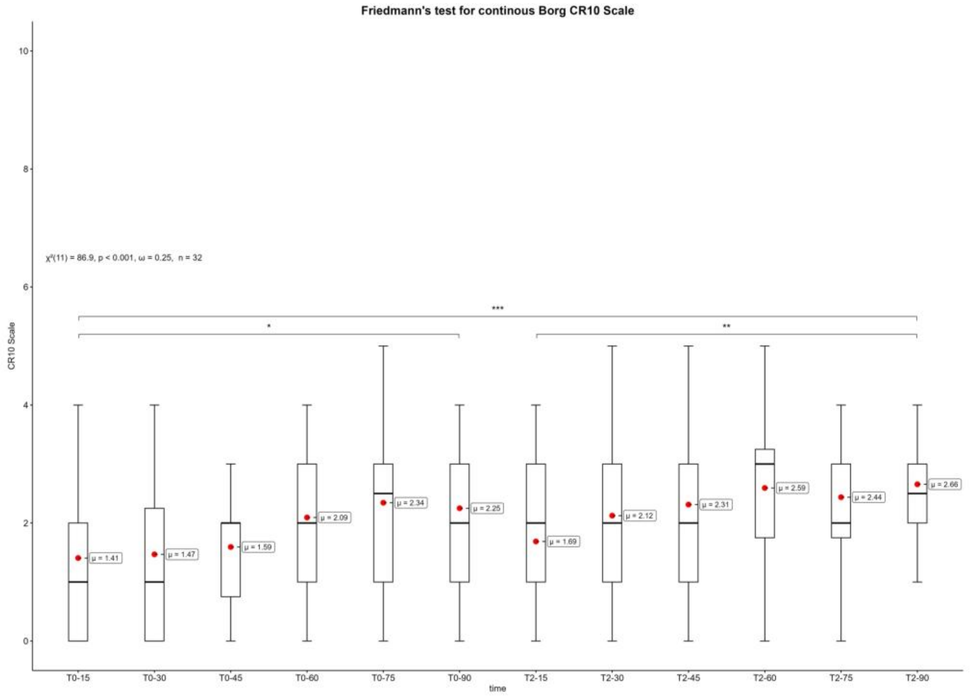

FIGURE 8
Box plots of the borg scale during the competitive video gaming sessions every 15 min. T0-min = first competitive video gaming session, T2-min = second competitive video gaming session. *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$.

5 Conclusion

In summary, competitive video gaming of 3–4 h can negatively affect the perceived physical exertion and the perceived physical state of esports athletes. A passive break may provide short-term regeneration but cannot fully restore. Over time and with a lack of observation, this could result in health and performance limitations. In addition, breaks should incorporate physical activity to mitigate the additional negative consequences of sedentary behavior, such as in esports. Moreover, physical exercise and body perception should be a crucial part of esports training. For practical implications, esports athletes are recommended to regularly monitor their burden and exertion, especially during competitive video gaming. This could lead to improve body perception, which is essential in preventing overtraining, overuse injuries, and burnout. Therefore, further research should focus on examining the validity and reliability of common measures of (perceived) exertion in esports. Additionally, more studies are needed to objectively investigate the physical burdens experienced during competitive video gaming.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/ **Supplementary Material**.

Ethics statement

The studies involving humans were approved by Ethical committee of the German Sport University Cologne. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CT: Conceptualization, Data curation, Project administration, Visualization, Writing – original draft, Formal Analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing. MS: Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. IF: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

We would like to express our gratitude to all esports athletes who participated in the study, as well as to the esports associations, organizations, and individuals who supported the acquisition.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2024.1370485/full#supplementary-material

References

1. Newzoo. Global Games Market Report: Free Version (2023). Available online at: https://Newzoo.Com/Resources/Trend-Reports/Newzoo-Global-Games-Market-Report-2023-Free-Version (cited December 28, 2023).

2. Jenny SE, Manning RD, Keiper MC, Olrich TW. Virtual(ly) athletes: where esports fit within the definition of "sport". *Quest.* (2017) 69:1–18. doi: 10.1080/00336297.2016.1144517

3. Mcleod CM, Xue H, Newman JI. Opportunity and inequality in the emerging esports labor market. *Int Rev Sociol Sport.* (2022) 57:1279–300. doi: 10.1177/10126902211064093

4. Riatti P, Thiel A. The societal impact of electronic sport: a scoping review. *Ger J Exerc Sport Res.* (2022) 52:433–46. doi: 10.1007/S12662-021-00784-W

5. Soffner M, Bickmann P, Tholl C, Froböse I. Dietary behavior of video game players and esports players in Germany: a cross-sectional study. *J Health Popul Nutr.* (2023) 42:29. doi: 10.1186/S41043-023-00373-7

6. Difrancisco-Donoghue J, Balentine J, Schmidt G, Zwibel H. Managing the health of the esport athlete: an integrated health management model. *Bmj Open Sport Exerc Med.* (2019) 5:E000467. doi: 10.1136/Bmjsem-2018-000467

7. Nagorsky E, Wiemeyer J. The structure of performance and training in esports. *Plos One.* (2020) 15:E0237584. doi: 10.1371/Journal.Pone.0237584

8. Franks RR, King D, Bodine W, Chisari E, Heller A, Jamal F, et al. Aoasm position statement on esports, active video gaming, and the role of the sports medicine physician. *Clin J Sport Med.* (2022) 32:E221–9. doi: 10.1097/Jsm.0000000000001034

9. Law A, Ho G, Moore M. Care of the esports athlete. *Curr Sports Med Rep.* (2023) 22:224–9. doi: 10.1249/Jsr.0000000000001077

10. Mcnulty C, Jenny SE, Leis O, Poulus D, Sondergeld P, Nicholson M. Physical exercise and performance in esports players: an initial systematic review. *J Elect Gam Esp.* (2023) 1:14. doi: 10.1123/Jege.2022-0014

11. Leis O, Lautenbach F, Birch PD, Elbe A-M. *Stressors, Associated Responses, and Coping Strategies in Professional Esports Players: A Qualitative Study.* United Kingdom: International Journal of Esports (2022). Available online at: https://www.ijesports.org/article/76/html (cited December 30, 2023).

12. Leis O, Lautenbach F. Psychological and physiological stress in non-competitive and competitive esports settings: a systematic review. *Psychol Sport Exerc.* (2020) 51:101738. doi: 10.1016/J.Psychsport.2020.101738

13. Machado S, de Oliveira Sant'ana L, Cid L, Teixeira D, Rodrigues F, Travassos B, et al. Impact of victory and defeat on the perceived stress and autonomic regulation of professional esports athletes. *Front Psychol.* (2022) 13:987149. doi: 10.3389/Fpsyg.2022.987149

14. Tholl C, Bickmann P, Wechsler K, Froböse I, Grieben C. Musculoskeletal disorders in video gamers - A systematic review. *BMC Musculoskelet Disord.* (2022) 23:678. doi: 10.1186/S12891-022-05614-0

15. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (sbrn) - terminology consensus project process and outcome. *Int J Behav Nutr Phys Act.* (2017) 14:75. doi: 10.1186/S12966-017-0525-8

16. Zwibel H, Difrancisco-Donoghue J, Defeo A, Yao S. An osteopathic physician's approach to the esports athlete. *J Am Osteopath Assoc.* (2019) 119:756–62. doi: 10.7556/Jaoa.2019.125

17. Farič N, Yorke E, Varnes L, Newby K, Potts HW, Smith L, et al. Younger adolescents' perceptions of physical activity, exergaming, and virtual reality: qualitative intervention development study. *Jmir Serious Games.* (2019) 7:E11960. doi: 10.2196/11960

18. Ward MR, Harmon AD. Esport superstars. *J Sports Econom.* (2019) 20:987–1013. doi: 10.1177/1527002519859417

19. Riot Games. Worlds 23: 2023 World Championship Rules V1.0. Available online at: https://Assets.Contentstack.Io/V3/Assets/Bltad9188aa9a70543a/Blt9e45826da232267a/652490b584295ea6b6944c76/2023_World_Championship_Ruleset_Vfinal_En.Pdf (cited April 24, 2024).

20. Esl Gaming Gmbh. The Ultimate Counter-Strike Competition: Game Specific Rules (2024). Available online at: https://pro.eslgaming.com/tour/cs/#rules (cited June 16, 2024).

21. Riot Games. Valorant College: 2022-2023 College Valorant Season Official Rules (2022). Available online at: https://Rsaa.Riotgames.Com/Wp-Content/Uploads/2022/09/2022-2023-College-Valorant-Season-Official-Rules.Pdf (cited April 16, 2024)

22. Beckmann K, Glemser A, Heckel C, von der Heyde C, Hoffmeyer-Zlotnik J, Hanefeld U. Demographische Standards.: Eine Gemeinsame Empfehlung Des Adm, Arbeitskreis Deutscher Markt- Und Sozialforschungsinstitute E.V., Der Arbeitsgemeinschaft Sozialwissenschaftlicher Institute E.V. (Asi) Und Des Statistischen Bundesamtes. [Demographical Standards-A Common Recommendation Of The Adm Working Group Of German Market And Social Research Institutes, Working Grroup Of Social Science Institutes (Asi) And The German Federal Statistical Office (2016).

23. Liebers F, Freyer M, Freitag S, Dulon M, Hegewald J, Latza U. Fragebogen Zu Muskel-Skelett-Beschwerden (Fb*Msb). Bundesanstalt Für Arbeitsschutz Und Arbeitsmedizin (Baua)/Berufsgenossenschaft Für Gesundheitsdienst Und Wohlfahrtspflege (Bgw) (2022).

24. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon.* (1987) 18:233–7. doi: 10.1016/0003-6870(87)90010-X

25. Finger JD, Tafforeau J, Gisle L, Oja L, Ziese T, Thelen J, et al. Development of the European health interview survey - physical activity questionnaire (ehis-paq) to monitor physical activity in the European union. *Arch Public Health.* (2015) 73:59. doi: 10.1186/S13690-015-0110-Z

26. Sansano-Nadal O, Wilson JJ, Martín-Borràs C, Brønd JC, Skjødt M, Caserotti P, et al. Validity of the sedentary behavior questionnaire in European older adults using English, Spanish, German and Danish versions. *Meas Phys Educ Exerc Sci*. (2022) 26:1–14. doi: 10.1080/1091367x.2021.1922910

27. Borg G. *Borg's Perceived Exertion and Pain Scales*. Champaign, Il: Human Kinetics (1998). p. 104.

28. Kleinert J. Adjektivliste zur erfassung der wahrgenommenen körperlichen verfassung (wkv). *Zeitschrift Für Sportpsychologie*. (2006) 13:156–64. doi: 10.1026/1612-5010.13.4.156

29. Faul F, Erdfelder E, Lang A-G, Buchner A. G*power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. (2007) 39:175–91. doi: 10.3758/Bf03193146

30. R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation For Statistical Computing (2024).

31. Dunn P. Scientific Research And Methodology: An Introduction To Quantitative Research In Science And Health. (2023) Available online at: https://Bookdown.Org/Pkaldunn/Srm-Textbook (cited January 6, 2024).

32. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd edn Hillsdale, NJ: Erlbaum (1988).

33. Eisinga R, Heskes T, Pelzer B, Te Grotenhuis M. Exact P-values for pairwise comparison of friedman rank sums, with application to comparing classifiers. *BMC Bioinformatics*. (2017) 18:68. doi: 10.1186/S12859-017-1486-2

34. Tomczak M, Tomczak E. The Need To Report Effect Size Estimates Revisited. An Overview Of Some Recommended Measures Of Effect Size.

35. Williams A, Kamper SJ, Wiggers JH, O'brien KM, Lee H, Wolfenden L, et al. Musculoskeletal conditions may increase the risk of chronic disease: a systematic review and meta-analysis of cohort studies. *BMC Med*. (2018) 16:167. doi: 10.1186/S12916-018-1151-2

36. Ren K. Grand challenges in musculoskeletal pain research: chronicity, comorbidity, immune regulation, sex differences, diagnosis, and treatment opportunities. *Front Pain Res (Lausanne)*. (2020) 1. doi: 10.3389/Fpain.2020.575479

37. Difrancisco-Donoghue J, Jenny SE, Douris PC, Ahmad S, Yuen K, Hassan T, et al. Breaking up prolonged sitting with A 6 min walk improves executive function in women and men esports players: a randomised trial. *BMJ Open Sport Exerc Med*. (2021) 7:E001118. doi: 10.1136/Bmjsem-2021-001118

38. Chandrasekaran B, Pesola AJ, Rao CR, Arumugam A. Does breaking up prolonged sitting improve cognitive functions in sedentary adults? A mapping review and hypothesis formulation on the potential physiological mechanisms. *BMC Musculoskelet Disord*. (2021) 22:274. doi: 10.1186/S12891-021-04136-5

39. Riot Games. Matchmaking And Autofill (2023) Available online at: https://Support-Leagueoflegends.Riotgames.Com/Hc/En-Us/Articles/201752954-Matchmaking-And-Autofill (cited January 5, 2024).

40. Bayrakdar A, Yıldız Y, Bayraktar I. Do E-athletes move? A study on physical activity level and body composition in elite E-sports. *PES*. (2020) 24:259–64. doi: 10.15561/20755279.2020.0501

41. Waongenngarm P, Van Der Beek AJ, Akkarakittichoke N, Janwantanakul P. Perceived musculoskeletal discomfort and its association with postural shifts during 4-H prolonged sitting in office workers. *Appl Ergon*. (2020) 89:103225. doi: 10.1016/J.Apergo.2020.103225

42. Chrismas BC, Taylor L, Cherif A, Sayegh S, Bailey DP. Breaking up prolonged sitting with moderate-intensity walking improves attention and executive function in qatari females. *PLoS One*. (2019) 14:E0219565. doi: 10.1371/Journal.Pone.0219565

43. Saunders TJ, Atkinson HF, Burr J, Macewen B, Skeaff CM, Peddie MC. The acute metabolic and vascular impact of interrupting prolonged sitting: a systematic review and meta-analysis. *Sports Med*. (2018) 48:2347–66. doi: 10.1007/S40279-018-0963-8

D. Studie III: Wrist extensor fatigue and game-genre-specific kinematic changes in esports athletes: a quasi-experimental study

Tholl *et al. BMC Sports Science, Medicine and Rehabilitation* (2025) 17:261
https://doi.org/10.1186/s13102-025-01305-0

BMC Sports Science, Medicine and Rehabilitation

RESEARCH Open Access

Wrist extensor fatigue and game-genre-specific kinematic changes in esports athletes: a quasi-experimental study

Chuck Tholl[1*], Lasse Hansen[2] and Ingo Froböse[1]

Abstract

Background Muscular fatigue critically affects health, performance, and safety in daily activities and sports. Esports or competitive gaming involves prolonged sitting and repetitive upper extremity movements, increasing the risk of muscular fatigue. Sustained activity may contribute to long-term musculoskeletal disorders (MSD). Despite this risk, biomechanical analyses in esports remain limited. This study examines muscular fatigue and wrist kinematics in esports athletes across different video game genres.

Methods Thirty-two healthy male esports athletes (23.8 ± 3.4 years) participated in two 90–120-minute competitive video gaming sessions, separated by a 10-minute passive sitting break. Surface electromyography (EMG) of the upper trapezius and wrist extensors, as well as wrist kinematics, were recorded. The median frequency (MDF) and root mean square (RMS) were used to quantify muscular fatigue. Statistical analyses included mixed ANOVA, one-way repeated measures ANOVA, and robust ANOVA with Bonferroni correction.

Results Repeated measures ANOVA indicated significant decreases in the MDF and RMS of the wrist extensors over time ($p < 0.001$). For the upper trapezius, only the right-side MDF showed a significant decrease over time; however, post-hoc analysis did not confirm this effect. Mixed ANOVA revealed no interaction between time and video game genre on kinematic data. First-person shooter players exhibited significantly greater cumulative distances ($p = 0.006$) and velocity zero-crossings ($p = 0.043$) than multiplayer online battle arena players in robust ANOVA.

Conclusions The findings indicate a progressive increase in wrist extensor fatigue over time, whereas wrist kinematics vary by video game genre but remain unaffected by time. The lack of neuromuscular recovery post-break suggests the potential for cumulative muscular fatigue. These repetitive loads could increase the risk of MSD. Therefore, implementing preventive training strategies and regular active breaks may help mitigate these effects in esports athletes.

Keywords Video games, Overuse syndrome, Biomechanics, Motion capture, Screen-based activity, Physical demands

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Background

Competitive video gaming, known as electronic sports (esports), attract millions of spectators, thousands of esports athletes and is an essential element of today's youth culture [1]. In contrast to recreational video game players, esports athletes train specifically to reach the highest performance levels and to compete in tournaments against other human players under specific regulations [2]. In particular, esports performance requires psychological-cognitive and communicative abilities as well as mechanical skills [3]. To reach this high stage of performance esports athletes exercise between 4 and 10 h/day depending on their skill level and game genre [4, 5]. As esports and video gaming are predominantly sedentary activities [6], esports athletes are faced with increased sitting times which are associated with several negative health outcomes [7, 8].

Requirements and musculoskeletal loading of esports athletes are comparable to those of other sedentary populations with high cognitive demands, such as computer workers, pianists or air traffic controllers [9, 10]. These populations have a higher risk for work- or practice-related musculoskeletal disorders [11–13]. Those occupational groups perform activities which require repetitive movements of the upper limbs and increased actions per minute (APM) to perform at high levels [10]. In esports, APM refers to the number of mouse clicks and keystrokes used to control the virtual environment. Depending on the game genre, esports athletes can reach over 500 APM [14]. Such repetitive movements pose a risk for muscular fatigue if they are executed continuously without breaks [15, 16]. In the short term this may lead to declines in performance [17, 18] and to an increase in perceived exertion [19]. Over the long term, muscular fatigue may contribute to adverse health outcomes, particularly overuse injuries or musculoskeletal disorders (MSDs) [20, 21]. A systematic review demonstrated that video gaming for three or more hours a day was associated with higher rates of reported MSDs [6]. However, the majority of the included studies were cross-sectional surveys, which limit the causal inference. MSDs result from a combination of factors, with biomechanical stress playing a particularly important role alongside psychosocial, socioeconomic, and environmental risks [12]. These include postural problems, high force exertions, highly repetitive tasks, ergonomic aspects and muscular fatigue [12, 21, 22]. In particular, highly repetitive movements and muscular fatigue have been observed in esports, but have not been rigorously studied [23].

Muscular fatigue is defined as a reduction in maximal force or power production in response to contractile activity and can be separated into central and peripheral components [20, 24]. Whereas central fatigue influences voluntary activation of muscle from within the central nervous system, peripheral fatigue is related to the neuromuscular junction and impair the contractile function of muscle [18]. The impact of video gaming on muscular fatigue has been investigated in only a limited number of studies [25–27]. Two studies demonstrated an increase in muscular fatigue after 20–30 min of smartphone gaming in the back [26] and in thumb muscles [27] of non-gamers. Divergent results were demonstrated after 1 h of mouse clicking task with gamers and non-gamers [25]. The study showed an increase in electrical activity but no alterations in frequency parameters on average, which led the authors to conclude that muscular fatigue was not observed. Overall, monotonous computer work could lead to increased muscular fatigue, if performed continuously [15, 28]. It can be reasonably deduced that the esports environment has the potential to induce muscular fatigue.

One potential contributing factor to muscular fatigue in esports is the kinematic structure of the activity itself. Studies observed faster hand acceleration in professionals compared to amateurs [29, 30]. Additionally, professionals show more accurate hand and elbow movements in the mouse arm [29]. Differences in kinematic patterns can also be seen across various game genres. Specifically, first-person shooter (FPS) and multiplayer online battle arena (MOBA) players showed significantly higher hand accelerations, repetitive motions and larger cumulative travel distances than adventure players [31]. Consequently, such movement patterns could lead to muscular fatigue. However, the existing studies do not fully reflect the real-world conditions in which esports athletes compete. Either only specific aspects of gameplay are tested, or the time periods studied are too short.

Therefore, the main objective of the current study is to explore the effects of competitive video gaming on muscular fatigue and wrist kinematics. The two primary hypotheses are: (1) muscular fatigue increases over time; and (2) wrist kinematics differ between video game genres and across time. The sub-hypothesis is that (3) mouse sensitivity acts as a co-factor influencing kinematic outcomes. The results may offer a better understanding of contributing factors for physical strains in esports. Moreover, these findings may contribute to the enhancement of holistic training practices while also supporting the development and application of preventive and rehabilitative strategies.

Materials and methods

Study design

This quasi-experimental study followed a repeated-measures, within- and between-group, non-randomized design to minimize individual variability [19]. The study was implemented at the Institute of Movement Therapy and Movement-oriented Prevention and Rehabilitation at the German Sport University Cologne. Between June and December 2023, esports athletes were recruited for a five-to six-hour investigation. They participated in two competitive video gaming sessions of 90–120 min, separated by a 10-minute passive sitting break (Fig. 1). Participants played only their primary game from one of two genres (FPS or MOBA) during both sessions, using their personal gaming accounts. Genre or game switching was not permitted. The protocol followed the ethical principles of the Declaration of Helsinki and was approved by the ethics committee of the German Sport University Cologne (reference: 093/2023).

Participants

The a priori power analysis estimated a minimum required sample size of $N = 24$ for mixed and repeated measures one-way ANOVA [32], considering a mean effect size (f) of 0.25, a significance level (α) of < 0.05, and a power (1-β) of 0.8. To account for potential participant dropout, we implemented an over-recruitment strategy of approximately 30%. This approach was intended to preserve statistical power and ensure complete data collection despite expected attrition [33]. A total of 32 healthy male esports athletes from Germany, aged between 18 and 35 years, participated in this study. Esports athletes were defined as those ranked in the top 20% of their respective video game's ranking system. Due to the absence of a standardized definition and classification of esports athletes [34], participants were categorized based on their competitive ranking. Specifically, those in the top 1% were classified as professionals, while all others were considered amateurs. Participants engaged in computer-based MOBA or FPS video games, using a computer mouse and keyboard. The mouse operation was conducted with the right hand, and the mouse sensitivity was set between 400 and 3000 dots per inch (DPI). Participants were excluded if they reported acute/chronic upper body musculoskeletal disorders, severe migraines, epilepsy, or significant physical or cognitive stress on the day before [19]. Participants were recruited through social media (*Discord*, *Instagram*, *LinkedIn*), in person at gaming venues and universities in Cologne, and via esports organizations. Recruitment was open to individuals of all gender identities; however, biological sex was also recorded and used in the analysis due to the physiological focus of the study.

Procedure

At the beginning of the examination, eligibility was verified, and anthropometric data were collected. Participants were instructed to refrain from cognitively or physically demanding activities on both the day prior to and the day of testing. Additionally, they were asked to abstain from alcohol for at least 12 h, avoid caffeinated beverages for five hours, and not to apply any lotions or creams on the day of the test. For electromyographic (EMG) analysis, the extensor digitorum communis and trapezius descendens were prepared according to *SENIAM* guidelines [35]. Passive reflective markers were then placed on the upper body and upper limb for kinematic data recording. Participants were asked to complete a partially standardized online questionnaire at the testing station to collect demographic data, health status, physical activity, musculoskeletal disorders and video gaming behavior. Physical activity was assessed with the *European Health Interview Survey - Physical Activity Questionnaire* (EHIS-PAQ) [36]. A comprehensive description of the questionnaire used in the current study is available in our previous publication [19]. The testing station consisted of an adjustable chair without armrests to allow for better hip motion capture and no headrest, an adjustable desk, ten motion capture cameras (*Miqus M3* & *Oqus 100*, *Qualysis*) and a provided gaming setup described in detail in the appendix. To standardize the parameters of video game exposure the participants were not allowed to play on personal hardware. Fig. 2 shows the standardized testing station. Additional photo material of the real experimental setup can be found in the appendix (Supplementary Figs. 12–13).

Prior to the start of the measurement, participants were asked to do their best to win the games. Subjects were required to play ranked matches on their primary

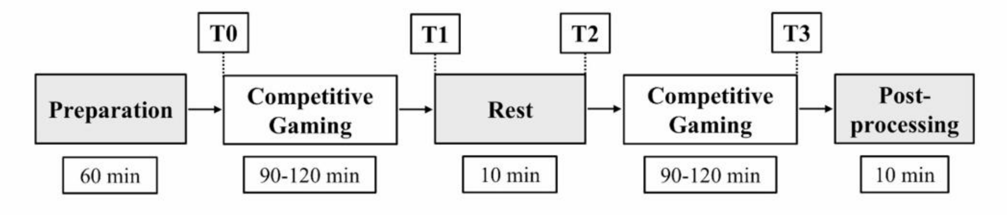

Fig. 1 Study design. T0 = before first competitive video gaming sessions; T1 = after first competitive video gaming sessions and before rest; T2 = after rest and before second competitive video gaming sessions; T3 = after second competitive video gaming sessions

Fig. 2 Standardized testing station with 10 motion capture cameras

accounts in a self-selected MOBA (*League of Legends*, *Defense of the Ancients 2*) or FPS (*Counter-Strike*, *Valorant*, *Overwatch*, *Rainbow Six Siege*) video game, to simulate typical tournament stress conditions. Internet connectivity was stable throughout all sessions. No latency issues or disconnections were observed by the research team, and none of the participants reported any connectivity-related disturbances during gameplay. EMG and kinematic data were recorded continuously during the competitive video gaming sessions and saved in 15-minute intervals. To meet the 90-minute minimum for data collection, participants had to play multiple rounds of the game, which typically lasted 25–45 min. Depending on the length of each game, sessions ranged from 90 to 120 min. After 120 min data recordings were stopped. Competitive video gaming sessions were interrupted by a 10-minute passive sitting [19], which reflects the average break between tournament games [37–39]. During the break, the consumption of alcoholic or caffeinated beverages and smoking was explicitly prohibited, with no other restrictions on food or caloric intake. A 5-minute passive sedentary recovery period was included in the study after the second competitive video game session.

Data collection & processing

EMG data was collected at 2000 Hz with a wireless system (*Ultium, Noraxon*) [40]. Four dual Ag/AgCl electrodes with an interelectrode distance of 20 mm were placed on the trapezius descendens and the extensor digitorum communis (Fig. 3). Due to the high probability of cross-talk in the analysis of the extensor digitorum [41], the term wrist extensors will be used in the remainder of this article. The raw data was bandpass (4th order recursive Butterworth, 4–450 Hz) and notch filtered (50 Hz) to eliminate power line interference. The EMG amplitude or the Electrical Activity (EA) was calculated by summing up the absolute values of the root mean square (RMS) samples for 10-s periods [42]. RMS values were normalized to isometric maximal voluntary contraction (MVC), in accordance with established guidelines [43]. Each muscle underwent three isometric MVC trials, which last five seconds, with about 30 s rest intervals between attempts [15, 44]. The EMG signal was segmented into 400 ms moving windows, RMS values were computed for each window, and the peak RMS value from each trial was identified. The highest value recorded across the three trials was used for normalization. The evaluation of both muscle groups was conducted in a seated position. For upper trapezius testing, participants were instructed to perform an isometric shoulder shrug in a neutral shoulder position while holding a strapped grip with the arm extended. Wrist extensor testing was performed with the forearm placed on an elevated surface, the shoulder in a neutral position, and the wrist maintained in approximately 20° of extension. The participants were instructed to extend their back of the hand against a fixed strap. This wrist posture was chosen to approximate the muscle's

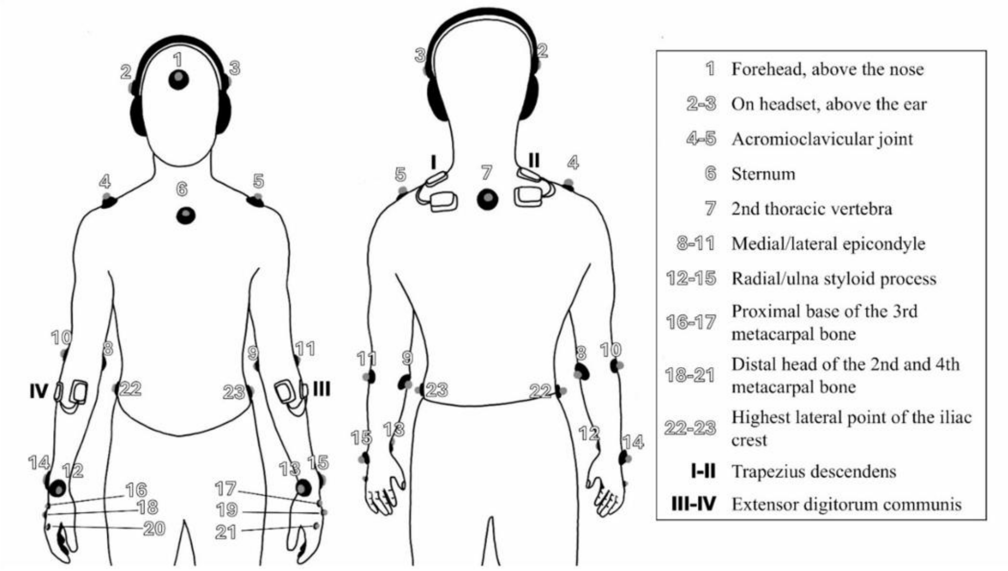

Fig. 3 Marker and sensor placement

optimal length on the length–tension curve and to replicate wrist positioning commonly observed esports participation [44, 45]. Prior to MVC testing, participants completed a brief standardized warm-up to activate the relevant muscles without inducing fatigue. The warm-up protocol consisted of 20 repetitions of wrist and shoulder circumductions in both directions, followed by dynamic stretching exercises: ten repetitions of wrist flexion and extension, and ten lateral dynamic stretches targeting the upper trapezius on each side. To analyze the power spectrum of EMG the median frequency (MDF) was calculated using Fast Fourier Transformation for 10-s periods [42]. MDF and RMS were visually inspected for artefacts. Non-physiological artifacts were spline interpolated [46].

Kinematic data was collected at 150 Hz with a marker based mocap system (*Qualisys Track Manager*, version 2020.2) [47]. Twenty-three passive reflective markers were attached to the participants using an adapted version of the *Qualisys* sports marker set (Fig. 3) [48]. Markers on the head, torso, and upper limbs were included as required by the kinematic model and may be utilized in subsequent analyses. No additional markers were attached to the gaming equipment or the testing station. Recording gaps of up to 30 frames were automatically filled using polynomial methods, while larger gaps were filled with relational rigid body gap-filling in *Qualisys Track Manager* [47].

Outcomes

To observe muscular fatigue, the EMG amplitude and power spectrum were analyzed. In particular, a temporal downshift in the power spectrum is commonly associated with muscular fatigue [49]. To ensure greater validity, the EMG amplitude was also analyzed, as a simultaneous increase in amplitude is indicative of muscle fatigue as well [42, 50].

The analysis of the kinematic data was informed by a previous study in order to ensure greater comparability [31]. The primary outcome parameters were: (1) the area of displacement (AoD), defined by an ellipse representing 95% of the mouse movement within the x-y axes on the table; (2) the cumulative distance traveled by the mouse hand during the different competitive games; and (3) the number of velocity zero-crossings of the mouse hand along the x-axes. Additionally, the time spent in pre-defined wrist joint angles was analyzed to identify potentially harmful positions, as defined by the Institute for Research and Testing of the German Social Accident Insurance [51]. Due to the lack of a standardized starting position, the respective mean wrist joint angle for each participant was used as the neutral position (0°).

Furthermore, an interaction analysis was conducted to investigate the effect of mouse sensitivity on kinematic data. Therefore, the "effective DPI" (eDPI), derived from the product DPI and of ingame mouse sensitivity, was calculated and z-transformed to facilitate comparisons across video game genres.

Statistical methods

The statistical analysis was conducted using the *RStudio* software (version 4.3.1) [52]. Due to the variable length of competitive video gaming sessions, only the first (_1) and the last game (_2) of each session were analyzed. These analyses include the first and last 5 min of each respective game. Single extreme outliers were excluded if they exceeded or fell below three times the interquartile range [53]. Descriptive statistics are presented, including the mean and standard deviation (SD) values. Baseline group differences were evaluated based on the distribution and scale of the variables. Continuous variables were tested using either an *unpaired t-test* or the *Wilcoxon rank-sum test*, depending on normality and variance assumptions. Categorical variables were analyzed using *Fisher's exact test*.

For the ANOVAs, normality at each measurement time for each variable and group was visually assessed using quantile-quantile (QQ) plots. Even if normal distribution is violated, the ANOVA remains robust [54, 55]. QQ plots for each variable are included in the appendix (Supplementary Figs. 1–11). In addition, homogeneity of variances was checked visually and homogeneity of covariances with the *Box's M-Test* for the mixed ANOVA. If either of these requirements were violated, a robust mixed ANOVA was used. Sphericity was tested using *Mauchly's test*, and if the assumption was violated ($p \leq 0.05$), the *Greenhouse-Geisser* ($\varepsilon < 0.75$) or *Huynh-Feldt* ($\varepsilon \geq 0.75$) correction was applied [56]. Changes over time were tested with *Bonferroni* post-hoc analysis. Differences between groups were evaluated with the independent *t-Test*. Effect sizes were calculated by using *Cohen's d* and interpreted as small = 0.2, moderate = 0.5 and large = 0.8 effect [57]. The interaction with z-transformed eDPI was analyzed using robust regression analysis with MM-estimators, as assumptions of the standard model were violated. The significance level for all analyses was set at $p < 0.05$. In line with the open science principle, all data as well as the R-syntax will be available after one year of publication.

Table 1 Sample characteristics and baseline differences

	FPS (*n* = 10)	MOBA (*n* = 22)	*p*-value
Age [years]	24.9 ± 4.28	23.3 ± 2.82	0.473[w]
Height [cm]	181 ± 5.33	180 ± 7.32	0.610[w]
Body mass [kg]	76.1 ± 10.3	83 ± 15	0.198[t]
BMI [kg/m²]	23.1 ± 2.54	25.6 ± 3.9	0.064[w]
BMI categories, n (%)			0.305[f]
Underweight	0 (0%)	0 (0%)	
Normal weight	8 (80%)	11 (50%)	
Overweight	2 (20%)	9 (40.9%)	
Obesity	0 (0%)	2 (9.1%)	
Total Physical Activity [min/week]	267.5 ± 173.1	326.14 ± 380.44	0.728[w]
> 150 min, n (%)	7 (70%)	13 (59.1%)	0.703[f]
> 300 min, n (%)	2 (20%)	10 (45.5%)	0.248[f]
MSTW, n (%)	8 (80%)	9 (40.9%)	0.061[f]
Video game playtime [h/day]	3.39 ± 1.89	3.7 ± 2.01	0.597[w]
Video game experience [years]	12 ± 4.9	12.9 ± 4.03	0.198[w]
Handedness, n (%)			0.090[w]
Left	0 (0%)	1 (4.6%)	
Right	8 (80%)	21 (95.5%)	
Both	2 (20%)	0 (0%)	
In-game rank Distribution, n (%)			**0.0247[w]**
1%	1 (10%)	8 (36.4%)	
5%	2 (20%)	8 (36.4%)	
10%	5 (50%)	1 (4.6%)	
20%	2 (20%)	5 (22.7%)	

FPS: first person shooter; MSTW: muscle strengthening twice a week; MOBA: multiplayer online battle arena; [f] Fisher's exact test; [t] t-test; [w] Wilcoxon rank-sum test; **Bold** = significant

Results

Participants

Table 1 displays the sample characteristics and baseline differences. A total of 32 male participants, predominantly right-handed (91%), with a mean age of 23.8 years (± 3.4), were included in the study, with no dropouts. The majority (69%) of participants were currently college students and held at least an A-Level degree (85%). On average, participants exhibited a BMI of 24.8 kg/m² (± 3.7). The mean weekly physical activity level among participants was 307.8 min/week (± 3.4). On average participants played video games 3.6 h/day (± 2.0) and had 12 years (± 4.3) of video game experience. The dominant video game genre was MOBA with 69%. The majority of participants (59%) achieved rankings within the top 5%, with MOBA players more frequently represented in higher competitive tiers than FPS players ($p = 0.025$). Additionally, the prevalence of musculoskeletal disorders is reported in detail in our previous study [19]. In that study, wrist and hand discomfort within the seven days prior to measurement was the most commonly reported issue (12.5%). Throughout the quasi-experimental study, no significant changes in discomfort or pain were observed [19].

Muscular fatigue

Median frequency

Fig. 4 shows the violin plots for the MDF of the recorded muscles during the competitive video gaming sessions. The results of the repeated measures ANOVA indicate significant differences in the MDF of the right trapezius ($p = 0.015$, $\eta^2 = 0.14$), the left wrist extensors ($p < 0.001$, $\eta^2 = 0.23$) and the right wrist extensors ($p < 0.001$, $\eta^2 = 0.28$). The post-hoc tests revealed that the MDF of the

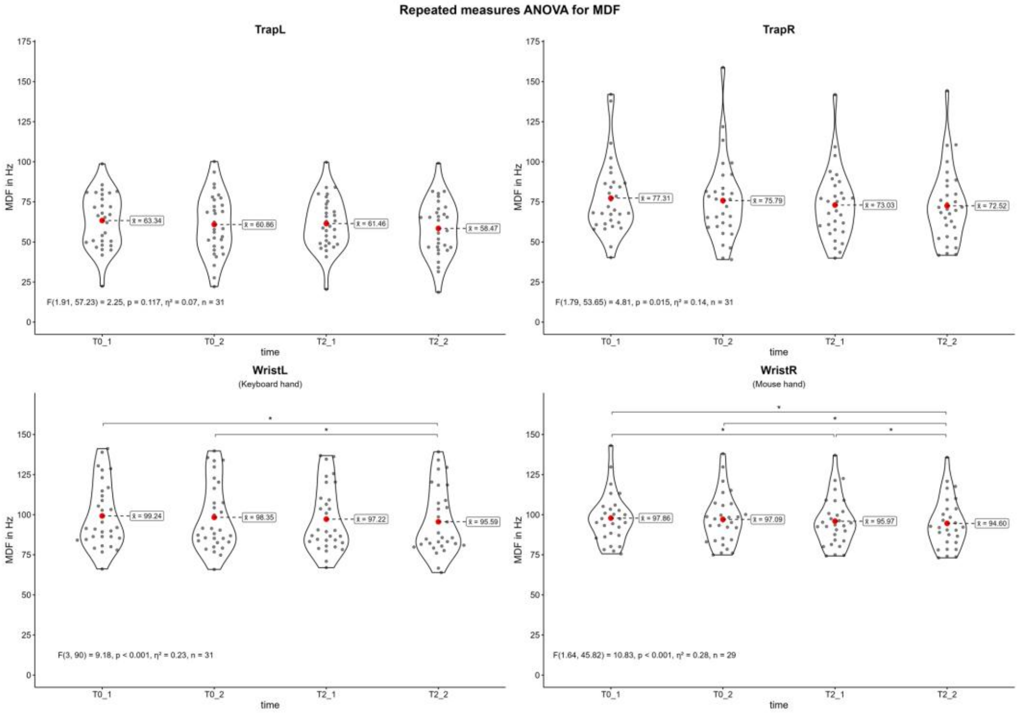

Fig. 4 Violin plots of the median frequency (MDF) during the competitive video gaming sessions. Trap = upper trapezius; Wrist = wrist extensor; L = left side; R = right side; T0 = first competitive session, T2 = second competitive session, _1 = first game, _2 = last game; *: $p \leq 0.05$

right trapezius did not differ between measurements. In contrast, both wrist extensors showed significant changes between the first and last (T0_1 vs. T2_2), as well as the second and last measurement (T0_2 vs. T2_2). Overall, there was a decrease in MDF over time. The MDF of the left wrist extensor decreased from 99.24 Hz (T0_1) to 95.59 Hz (T2_2) (-3.7%). The MDF of the right wrist extensor decreased from 97.86 Hz (T0_1) to 94.60 Hz (T2_2) (-3.3%). The effect sizes of all significant changes can be considered moderate. The results of all post-hoc tests are shown in the appendix (Supplementary Tables 2–4).

Electric amplitude

Fig. 5 shows the violin plots for the normalized RMS of the different muscles during the competitive video gaming sessions. The results of the repeated measures ANOVA indicate significant differences in the normalized RMS of both wrist extensors (left: $p < 0.001$, $\eta^2 = 0.26$; right: $p < 0.001$, $\eta^2 = 0.50$). The post-hoc tests revealed significant differences between the first and the last (T0_1 vs. T2_2) and the first and the third measurement (T0_1 vs. T2_1). Additionally, the left wrist extensor showed a significant difference between the second and final measurements (T0_2 vs. T2_2), whereas the right wrist extensor showed a significant difference between the first and second measurements (T0_1 vs. T0_2). Overall, there was a decrease in EA over time. The normalized RMS of the left wrist extensor decreased from average 4.62% (T0_1) to 3.89% (T2_2) (-15.8%) with moderate effect sizes. The normalized RMS of the right wrist extensor decreased from 5.64% (T0_1) to 4.70% (T2_2) (-16.6%) with large effect sizes. The results of all post-hoc tests are shown in the appendix (Supplementary Tables 5–6).

Kinematic data

Wrist angles

Table 2 presents the percentage of time the mouse hand spent in various wrist angles in radial or ulnar adduction across different video game genres and measurement times. In both video game genres and across all measurement times, the first range of joint angle positions (-10° to 10°) are predominantly utilized, accounting for over 95% of the time. This zone is classified as the neutral zone [51]. FPS players spent less time in the first range of joint

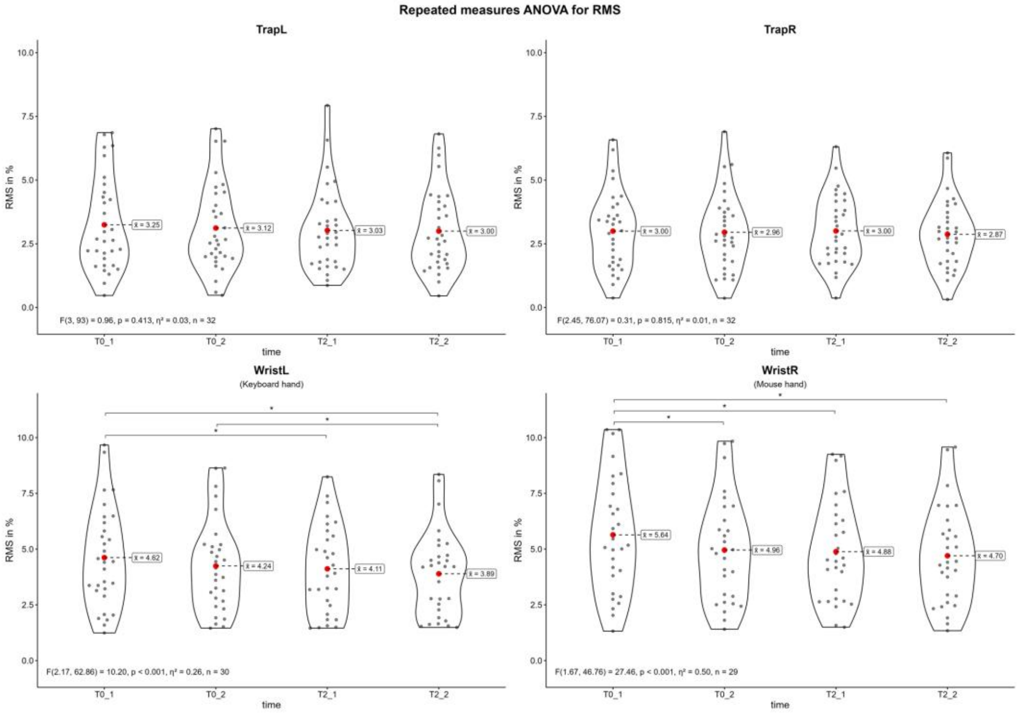

Fig. 5 Violin plots of the root mean square (RMS) during the competitive video gaming sessions. Trap = upper trapezius; Wrist = wrist extensor; L = left side; R = right side; T0 = first competitive session, T2 = second competitive session, _1 = first game, _2 = last game; *: $p \leq 0.05$

Table 2 Percentage of time mouse hand spent in radial or ulnar adduction by genre and time

	FPS (*n* = 10)			**MOBA (*n* = 22)**		
	-10° to 10°	**-10° to -25° and 10° to 15°**	**< -25° and >15°**	**-10° to 10°**	**-10° to -25° and 10° to 15°**	**< -25° and >15°**
T0_1	95.95%	2.35%	1.70%	99.44%	0.36%	0.20%
T0_2	97.24%	1.99%	0.77%	98.04%	0.69%	1.26%
T2_1	96.41%	2.13%	1.46%	98.65%	0.81%	0.54%
T2_2	95.82%	1.95%	2.23%	97.20%	1.86%	0.94%

FPS: first person shooter; MOBA: multiplayer online battle arena. Positive degrees = radial adduction; Negative degrees = ulnar adduction

angle positions compared to MOBA players across measurements. Consequently, FPS players allocated more time to the second and third joint angle positions, except for the second measurement (T0_2).

Cumulative distance

Table 3 shows the descriptive and inferential statistics of the cumulative distance across video game genres and measurement times. Overall, the cumulative distance decreased over time in FPS players from the first to the fourth measurement (-21.49%). In contrast, for MOBA players, it initially decreased to the third measurement (-11.92%) before increasing at the fourth measurement (+8.51%). The robust mixed ANOVA showed no significant interaction effect (Q(3, 4.58) = 1.80, $p = 0.272$). Similarly, no significant within-subject effect for time was observed (Q(3, 4.58) = 1.02, $p = 0.463$). However, a significant between-subject effect for the video game genre was identified (Q(1, 5.29) = 18.94, $p = 0.006$). In particular, FPS players exhibited significantly greater mean cumulative distance compared to MOBA players.

Table 3 Robust mixed ANOVA for cumulative distance [m]

	FPS ($n=10$)		MOBA ($n=22$)	
	M	SD	M	SD
T0_1	63.34	39.45	19.03	8.44
T0_2	55.10	32.72	19.48	10.85
T2_1	55.05	32.24	16.76	7.01
T2_2	49.73	34.66	20.65	7.84
ANOVA Results				
Group	Q(1, 5.29) = 18.94, ***p* = 0.006**			
Time	Q(3, 4.58) = 1.02, *p* = 0.463			
Interaction	Q(3, 4.58) = 1.80, *p* = 0.272			

FPS: first person shooter; MOBA: multiplayer online battle arena

Table 4 Robust mixed ANOVA for area of displacement [cm²]

	FPS ($n=10$)		MOBA ($n=22$)	
	M	SD	M	SD
T0_1	68.66	54.91	32.05	23.67
T0_2	85.59	58.85	32.99	27.24
T2_1	83.07	48.76	34.20	30.96
T2_2	91.41	74.05	38.04	30.15
ANOVA Results				
Group	Q(1, 5.47) = 5.58, ***p* = 0.06**			
Time	Q(3, 5.65) = 0.91, *p* = 0.49			
Interaction	Q(3, 5.65) = 0.65, *p* = 0.61			

FPS: first person shooter; MOBA: multiplayer online battle arena

Table 5 Mixed ANOVA for total number velocity zero-crossings

	FPS ($n=10$)		MOBA ($n=22$)	
	M	SD	M	SD
T0_1	1167.00	476.98	773.62	546.90
T0_2	994.50	356.45	723.71	485.24
T2_1	971.50	494.27	699.57	532.37
T2_2	1179.00	431.06	751.57	526.19
ANOVA Results				
Group	F(1, 29) = 4.47, ***p* = 0.043**, pes = 0.134			
Time	F(3, 87) = 1.36, *p* = 0.26, pes = 0.045			
Interaction	F(3, 87) = 4.46, *p* = 0.713, pes = 0.016			

FPS: first person shooter; MOBA: multiplayer online battle arena

Area of displacement

Table 4 presents the descriptive and inferential statistics for the AoD across video game genres and measurement times. Overall, the AoD increased from the first to the last measurement in both FPS (+ 33.13%) and MOBA (+ 18.69%) players, with notable differences observed between the two groups. The robust mixed ANOVA showed no significant interaction effect Q(3, 5.65) = 0.65, $p = 0.61$). Furthermore, neither the within-subject effect (Q(3, 5.65) = 0.91, $p = 0.49$) nor the between-subject effect Q(1, 5.47) = 5.58, $p = 0.06$) was statistically significant.

Zero-crossings

Table 5 shows the descriptive and inferential statistics for total number velocity zero-crossings across video game genres and measurement times. Overall, the number of zero-crossings decreased from the first to the third measurement in both FPS players (-16.75%) and MOBA players (-9.57%). At the fourth measurement, the zero-crossings increased again, exceeding the baseline value in FPS players (101.03%) and approaching it in MOBA players (97.14%). The mixed ANOVA showed no significant interaction effect (F(3, 87) = 4.46, $p = 0.713$, pes = 0.016). Similarly, no significant within-subject effect for time was observed (F(3, 87) = 1.36, $p = 0.26$, pes = 0.045). However, a significant between-subject effect for the video game genre was identified (F(1, 29) = 4.47, $p = 0.043$, pes = 0.134). Specifically, FPS players exhibited a significantly higher total number of velocity zero-crossings on average compared to MOBA players.

Interaction eDPI

The robust regression analysis revealed statistically significant negative correlations between z-transformed eDPI and cumulative distance (β = −5.02, SE = 1.39, t = − 3.60, $p < 0.001$) and AoD (β = −9.29, SE = 2.20, t = − 4.22, $p < 0.001$). This indicates that for each one-unit increase in eDPI, the cumulative distance decreased by approximately 5.02 cm and the AoD decreased by approximately 9.29 cm². No statistically significant relationship was observed between the number of zero-crossings and eDPI (β = −60.49, SE = 48.23, t = − 1.25, $p = 0.212$).

Discussion

The objective of this study was to examine the impact of competitive video gaming on muscular fatigue and wrist kinematics. The main findings partially support the primary hypothesis indicating that muscular fatigue increased over time in wrist extensors, as evidenced by a significant downshift in the EMG frequency spectrum. Atypically, this was accompanied by an RMS decrease. However, wrist kinematics differed only between video game genres but not across time or in interaction. On average, FPS players exhibited greater cumulative distances and higher numbers of velocity zero-crossings, and they also tended to cover larger AoDs. Notably, a 10-minute passive break between competitive gaming sessions did not effectively reduce physical load.

Muscular fatigue

Only wrist extensors demonstrated a significant decrease in MDF and RMS over time (Figs. 4 and 5). The MDF decreased about 3.7% in the left and 3.3% in right wrist extensors with a moderate effect size. This temporal downshift in the power spectrum is commonly associated with muscular fatigue [49]. This is plausible because of the nature of competitive video gaming and the involvement of the hands to interact with the virtual environment [6]. Similar findings are demonstrated in other video gaming exposure studies were smartphone gaming decreased MDF in the erector spinae [26] or extensor and abductor pollicis brevis [27]. Related effects can be found after prolonged keyboard typing [15] or piano tasks [9]. In contrast the trapezius descendants demonstrated a non-significant decrease of 7.7% on the left and 6.2% on the right side. The reasons for this may be a less involved activity compared to the hands or a higher variability between subjects indicated by a larger interquartile range (Fig. 2). Controverse findings where demonstrated after 40 min of sedentary computer work where the MDF decreased significantly in the upper trapezius [28]. In contrast to this and in line with current findings, smartphone gaming did not decreased MDF significantly [26].

The RMS was reduced by 15.8% in the left and 16.6% in right wrist extensors with large effect sizes. This contrasts other findings, which demonstrated muscular fatigue in a simultaneous decrease in MDF and increase in RMS according to the joint analysis of the spectral and amplitude (JASA) [28, 42]. The JASA method is based on the association between muscular force production and fatigue state, as well as the EMG amplitude and spectrum. Controverse effects were observed in similar studies with low-effort repetitive activities with an increase [9, 15, 28] or decrease [16, 58] in RMS over time. However, EMG amplitude is a highly task-dependent parameter. In high-intensity or maximal contractions, EMG amplitude typically increases over time due to the recruitment of additional motor units (MUs) to maintain the required force output, thereby compensating for fatigue in already active fibers [42, 59]. A similar trend has been observed in sustained submaximal contractions [9, 15]. JASA is based on the same principle of constant-force contractions [42], which may not reflect the load characteristics and intermittent nature of competitive video gaming. In contrast, intermittent, low-effort activities, may exhibit a decreases in EMG amplitude over time [16, 60]. Several mechanisms have been proposed in the literature to explain this observation, including limited recruitment of additional MUs, potentiation of muscle fibers, or MU rotation. It has been hypothesized that low-force tasks primarily activate only a small subset of the available MUs, which are predominantly slow-twitch (type I) fibers, often referred to as "Cinderella fibers" due to their continuous activation during low-intensity, sustained activities [61]. These motor units remain active until complete muscle relaxation, making them particularly susceptible to overuse and fatigue-related strain. Furthermore, the decline in EMG amplitude may be attributed to muscle fiber potentiation, whereby the muscle produces greater force per stimulus at a given level of neural input [62]. Potentiation is regarded as an initial phase in the progression of muscle fatigue. It is hypothesized that this phenomenon functions as a protective mechanism by enhancing muscular efficiency, that is, by increasing the force output per unit of neural input [16]. Another possible mechanism at low contraction levels is MU rotation [63, 64]. In this process, fatigued MUs temporarily deactivate while fresh MUs are recruited to sustain force output. If the newly recruited MUs generate less electrical activity, such as smaller or less active units, or if the net effect of this rotation does not lead to an increase in EMG amplitude, the RMS value may remain stable or even decline [64]. These neuromuscular adaptations, such as selective MU recruitment, potentiation, and rotation, can be more accurately characterized using high-density EMG (HD-EMG), which provides spatial resolution of MU activity [65]. Therefore, future studies investigating the underlying motor unit behavior during low-intensity, intermittent tasks, such as competitive gaming, should consider employing HD-EMG.

These physiological mechanisms may offer a potential explanation for the observed decline in EMG amplitude during low-effort, intermittent activities such as competitive video gaming. Notably, the nature of esports includes dynamic and irregular task demands that differ from standardized fatigue protocols. For example, esports athletes often experience brief periods of reduced muscular activity, such as during in-game respawns, between rounds, or while waiting in matchmaking queues, that allow partial recovery [19]. These intermittent recovery phases could reduce continuous neuromuscular loading, potentially influencing fatigue development and masking typical EMG fatigue patterns [16]. Therefore, the specific structural features of competitive video gaming may contribute to the deviation from traditional EMG fatigue signatures observed in constant-load tasks.

Wrist kinematics

FPS players move their mouse hands over significantly greater distances and exhibit higher numbers of zero-crossings (lateral movements of the wrist) than MOBA players (Tables 3 and 5). Additionally, FPS players tend to cover larger areas than MOBA players, although this difference was not statistically significant (Table 4). However, no effect of time was observed, which partially confirms the second hypothesis. The group differences may be explained by the use of lower mouse sensitivity settings in the FPS group, as FPS games require more precise movements than MOBA games [29]. Consequently, FPS players have to move their upper extremities more [31]. A negative relationship between eDPI and cumulative distances, as well as AoD, was observed in the current study. Therefore, it can be indirectly concluded that

FPS players use lower mouse sensitivity settings, confirming the sub-hypothesis. These findings suggest that the greater movement observed in FPS players is primarily performance-driven, resulting from genre-specific motor demands and strategic use of lower sensitivity settings to improve aiming precision. Furthermore, the current study demonstrated a significant difference in zero-crossings between FPS and MOBA player which is in contrast to other findings [31]. Additionally, the number of zero-crossings observed in the current study was substantially lower than in that prior study, where both FPS and MOBA players reached approximately 2,250 zero-crossings over a 10-minute period. One potential explanation for this discrepancy is the use of different measurement tools. The present study employed passive optical motion capture, whereas Dupuy et al. [31] used inertial measurement units, which may result in divergent sensitivity to movement characteristics. Additionally, a baseline difference in rank distribution was observed, with MOBA players more frequently represented in higher competitive tiers than FPS players, which could have influenced the group differences observed in the current study.

The presented kinematic data indicate continuous, highly repetitive, and large-scale movements over 3–4 h of competitive video gaming, with differences between FPS and MOBA players. This behavior could increase the risk of muscular fatigue [28]. In consideration of the present findings, this could explain why the wrist extensors fatigued significantly. Conversely, the upper trapezius only showed tendencies of muscular fatigue. In addition, a 10-minute passive break between competitive gaming sessions did not affect either muscular fatigue or kinematic parameters. Based on the current evidence break patterns should be more physically active to decrease muscular fatigue and perceived discomfort [28] and physical exertion [19]. Furthermore, active breaks could increase cognitive functions and consequently esports performance [66–68]. Additionally, the current study highlighted that even a single competitive video gaming session of 3–4 h increased muscular fatigue significantly. Considering the daily training habits of esports athletes, which range between 4 and 10 h/day [4, 5], this could contribute to MSDs in the long term [21]. Therefore, it is highly recommended for practitioners to not only schedule breaks, but also to plan specific break behaviors that include physical activity [69]. For an even greater preventive effect, regular exercise can prevent premature muscular fatigue and MSDs [6, 21].

Limitations

The results of this study must be interpreted in light of several limitations. First, the interpretation of EMG-based fatigue markers may be influenced by the structure of competitive gaming sessions. Participants experienced passive breaks while waiting in matchmaking queues, which sometimes lasted up to 10 min depending on in-game rank. These intermittent recovery periods, which reflecting real-world tournament conditions [37–39], may have attenuated muscle fatigue and contributed to the atypical RMS trends observed. Additionally, EMG analysis was conducted in the absence of force or task performance data, which limited the ability to link electrophysiological changes directly to functional fatigue. Potential EMG crosstalk between closely spaced wrist extensor muscles is another possible limitation, as it may confound muscle-specific signal interpretation [41]. Second, the absence of a standardized starting wrist position may have introduced variability in kinematic outcomes, particularly in zero-crossing analyses. Consequently, absolute joint angle measurements may have varied between individuals, potentially affecting the comparability of the kinematic data. Furthermore, two participants were classified as obese (BMI ≥ 30), which may have influenced individual neuromuscular or biomechanical responses. No subgroup analysis was conducted due to the small number.

Beyond these limitations, several methodological choices should also be acknowledged. The present study included only male esports athletes, reflecting current gender distributions in esports but limiting generalizability [5]. Future research should aim for more gender-diverse samples. The study did not include a control group, and randomization was not feasible, limiting causal inference. Finally, the distribution of group sizes was imbalanced (MOBA: $n = 22$; FPS: $n = 10$) due to the consecutive inclusion of participants based on their eligibility rather than stratification by game genre. This imbalance may have influenced the outcomes of between-group comparisons.

Conclusion

In summary, competitive video gaming for 3–4 h may induce muscular fatigue in esports athletes. Additionally, FPS players demonstrated significantly greater cumulative distances exhibited higher numbers of lateral wrist movements, and tended to cover larger AoDs than MOBA players. No effect of time was found for kinematic parameter. A passive break did not provide sufficient short-term regeneration for the observed parameters. Without additional physical activity or exercises, these physical demands could lead to higher risks of MSDs and consequently to earlier retirements for esports athletes. Practically, esports athletes are advised to regularly monitor their training habits, particularly their break schedules. Further research should evaluate different methods for analyzing muscular fatigue in esports, with particular emphasis on wavelet transformation. Additionally, different break activities should be compared to evaluate the best opportunities to reduce and avoid muscular fatigue, but also to enhance performance of esports athletes.

Abbreviations

AoD	Area of displacement
APM	Actions per minute
DPI	Dots per inch
eDPI	Effective dots per inch
Esports	Electronic sports
EMG	Electromyography
FPS	First-person shooter
HD-EMG	High-density electromyography
JASA	Joint analysis of the spectral and amplitude
MDF	Median frequency
MOBA	Multiplayer online battle arena
MSD	Musculoskeletal disorders
MVC	Maximal voluntary contraction
RMS	Root mean square
QQ plot	Quantile-quantile plot

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01305-0.

Supplementary Material 1

Acknowledgements

We would like to express our gratitude to all esports athletes who participated in the study, as well as to the esports associations, organizations, and individuals who supported the acquisition.

Author contributions

All authors contributed to the article and approved the submitted version. CT, LH, and IF conducted the investigation and developed the methodology. CT performed the formal analysis and managed project administration and resources. IF and CT supervised the study and validated the findings. CT and LH wrote the original draft, while CT, LH, and IF reviewed and edited the manuscript.

Funding

Open Access funding enabled and organized by Projekt DEAL. The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors one year after publication. All data and materials from this study will be available on the *Open Science Framework* (https://osf.io/zhy29/).

Declarations

Ethics approval and consent to participate

The study followed the ethical principles of the Declaration of Helsinki and was approved by the ethics committee of the German Sport University Cologne (reference: 093/2023). Written informed consent was obtained from all participants prior to participation in the study.

Consent for publication

Written informed consent was obtained from one participant for the publication of clinical images and associated information in this study.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

Received: 16 February 2025 / Accepted: 8 August 2025
Published online: 01 September 2025

References

1. Newzoo. Global Games Market Report: Free Version. 2023. https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version. Accessed 28 Dec 2023.
2. Jenny SE, Besombes N, Brock T, Cote AC, Scholz TM, editors. Routledge handbook of esports. London, New York: Routledge; 2025.
3. Nagorsky E, Wiemeyer J. The structure of performance and training in esports. PLoS ONE. 2020;15:e0237584. https://doi.org/10.1371/journal.pone.0237584.
4. DiFrancisco-Donoghue J, Balentine J, Schmidt G, Zwibel H. Managing the health of the eSport athlete: an integrated health management model. BMJ Open Sport Exerc Med. 2019;5:e000467. https://doi.org/10.1136/Bmjsem-2018-000467.
5. Soffner M, Bickmann P, Tholl C, Froböse I. Dietary behavior of video game players and esports players in germany: a cross-sectional study. J Health Popul Nutr. 2023;42:29. https://doi.org/10.1186/s41043-023-00373-7.
6. Tholl C, Bickmann P, Wechsler K, Froböse I, Grieben C. Musculoskeletal disorders in video gamers - a systematic review. BMC Musculoskelet Disord. 2022;23:678. https://doi.org/10.1186/s12891-022-05614-0.
7. Law A, Ho G, Moore M. Care of the esports athlete. Curr Sports Med Rep. 2023;22:224–9. https://doi.org/10.1249/JSR.0000000000001077.
8. Franks RR, King D, Bodine W, Chisari E, Heller A, Jamal F, et al. AOASM position statement on esports, active video gaming, and the role of the sports medicine physician. Clin J Sport Med. 2022;32:e221–9. https://doi.org/10.1097/JSM.0000000000001034.
9. Goubault E, Verdugo F, Pelletier J, Traube C, Begon M, Dal Maso F. Exhausting repetitive piano tasks lead to local forearm manifestation of muscle fatigue and negatively affect musical parameters. Sci Rep. 2021;11:8117. https://doi.org/10.1038/s41598-021-87403-8.
10. Borghini G, Ronca V, Vozzi A, Aricò P, Di Flumeri G, Babiloni F. Monitoring performance of professional and occupational operators. Handb Clin Neurol. 2020;168:199–205. https://doi.org/10.1016/B978-0-444-63934-9.00015-9.
11. Turner C, Goubault E, Maso FD, Begon M, Verdugo F. The influence of proximal motor strategies on pianists' upper-limb movement variability. Hum Mov Sci. 2023;90:103110. https://doi.org/10.1016/j.humov.2023.103110.
12. de Kok J, Vroonhof P, Snijders J, Roullis G, Clarke M, Peereboom K et al. Work-related musculoskeletal disorders: Prevalence, costs and demographics in the EU. 2019. https://osha.europa.eu/en/publications/work-related-musculoskeletal-disorders-prevalence-costs-and-demographics-eu/view. Accessed 5 Nov 2022.
13. Waongenngarm P, Areerak K, Janwantanakul P. The effects of breaks on low back pain, discomfort, and work productivity in office workers: A systematic review of randomized and non-randomized controlled trials. Appl Ergon. 2018;68:230–9. https://doi.org/10.1016/j.apergo.2017.12.003.
14. Migliore L, Beckman K. Upper extremity disorders in esports. In: Migliore L, McGee C, Moore MN, editors. Handbook of esports medicine. Cham: Springer International Publishing; 2021. pp. 17–70. https://doi.org/10.1007/978-3-030-73610-1_2.
15. Callegari B, de Resende MM, Da Silva Filho M. Hand rest and wrist support are effective in preventing fatigue during prolonged typing. J Hand Ther. 2018;31:42–51. https://doi.org/10.1016/j.jht.2016.11.008.
16. Hostens I, Ramon H. Assessment of muscle fatigue in low level monotonous task performance during car driving. J Electromyogr Kinesiol. 2005;15:266–74. https://doi.org/10.1016/j.jelekin.2004.08.002.
17. Huysmans MA, Hoozemans MJM, van der Beek AJ, de Looze MP, van Dieën JH. Fatigue effects on tracking performance and muscle activity. J Electromyogr Kinesiol. 2008;18:410–9. https://doi.org/10.1016/j.jelekin.2006.11.003.
18. Forman GN, Sonne MW, Kociolek AM, Gabriel DA, Holmes MWR. Influence of muscle fatigue on motor task performance of the hand and wrist: A systematic review. Hum Mov Sci. 2022;81:102912. https://doi.org/10.1016/j.humov.2021.102912.
19. Tholl C, Soffner M, Froböse I. How strenuous is esports? Perceived physical exertion and physical state during competitive video gaming. Front Sports Act Living. 2024;6:1370485. https://doi.org/10.3389/fspor.2024.1370485.
20. Wan J-J, Qin Z, Wang P-Y, Sun Y, Liu X. Muscle fatigue: general Understanding and treatment. Exp Mol Med. 2017;49:e384. https://doi.org/10.1038/emm.2017.194.

21. Gallagher S, Schall MC. Musculoskeletal disorders as a fatigue failure process: evidence, implications and research needs. Ergonomics. 2017;60:255–69. https://doi.org/10.1080/00140139.2016.1208848.
22. Schmidt K, Friedrichs P, Cornelsen HC, Schmidt P, Tischer T. Musculoskeletal disorders among children and young people: prevalence, risk factors and preventive measures: a scoping review. Luxembourg: Publications Office of the European Union; 2021.
23. Dupuy A, Campbell MJ, Harrison AJ, Toth AJ. On the necessity for biomechanics research in esports. Sports Biomech. 2024;1–13. https://doi.org/10.1080/14763141.2024.2354440.
24. Boyas S, Guével A. Neuromuscular fatigue in healthy muscle: underlying factors and adaptation mechanisms. Ann Phys Rehabil Med. 2011;54:88–108. https://doi.org/10.1016/j.rehab.2011.01.001.
25. Forman GN, Melchiorre LP, Holmes MWR. Impact of repetitive mouse clicking on forearm muscle fatigue and mouse aiming performance. Appl Ergon. 2024;118:104284. https://doi.org/10.1016/j.apergo.2024.104284.
26. Hanphitakphong P, Thawinchai N, Poomsalood S. Effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles in school students aged between 10–18 years. Cogent Eng. 2021. https://doi.org/10.1080/23311916.2021.1890368.
27. Wang D, Tang L, Wu H, Gu D. Analysis of the effect of overusing thumbs on smartphone games. J Int Med Res. 2019;47:6244–53. https://doi.org/10.1177/0300060519881016.
28. Ding Y, Cao Y, Duffy VG, Zhang X. It is time to have rest: how do break types affect muscular activity and perceived discomfort during prolonged sitting work. Saf Health Work. 2020;11:207–14. https://doi.org/10.1016/j.shaw.2020.03.008.
29. Park E, Lee S, Ham A, Choi M, Kim S, Lee B. Secrets of Gosu: Understanding Physical Combat Skills of Professional Players in First-Person Shooters. In: Kitamura Y, Quigley A, Isbister K, Igarashi T, Bjørn P, Drucker S, editors. CHI '21: CHI Conference on Human Factors in Computing Systems; 08 05 2021 13 05 2021; Yokohama Japan. New York, NY, USA: ACM; 2021. pp. 1–14. https://doi.org/10.1145/3411764.3445217
30. Li G, Wang M, Arippa F, Barr A, Rempel D, Liu Y, Harris Adamson C. Professional and High-Level gamers: differences in performance, muscle activity, and hand kinematics for different mice. Int J Human–Computer Interact. 2022;38:691–706. https://doi.org/10.1080/10447318.2021.1960742.
31. Dupuy A, Campbell MJ, Toth AJ. Differentiating right upper limb movements of esports players who play different game genres. Sci Rep. 2025;15:6498. https://doi.org/10.1038/s41598-025-90949-6.
32. Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39:175–91. https://doi.org/10.3758/bf03193146.
33. In J, Kang H, Kim JH, Kim TK, Ahn EJ, Lee DK, et al. Tips for troublesome sample-size calculation. Korean J Anesthesiol. 2020;73:114–20. https://doi.org/10.4097/kja.19497.
34. Bubna K, Trotter MG, Polman R, Poulus DR. Terminology matters: defining the esports athlete. Front Sports Act Living. 2023;5:1232028. https://doi.org/10.3389/fspor.2023.1232028.
35. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol. 2000;10:361–74. https://doi.org/10.1016/S1050-6411(00)00027-4.
36. Finger JD, Tafforeau J, Gisle L, Oja L, Ziese T, Thelen J, et al. Development of the European health interview Survey - Physical activity questionnaire (EHIS-PAQ) to monitor physical activity in the European union. Arch Public Health. 2015;73:59. https://doi.org/10.1186/s13690-015-0110-z.
37. Riot Games. OFFICIAL ERL RULEBOOK v2.0 2025 SEASON. 2024. https://cdn.sanity.io/files/dsfx7636/news/f068037e8869f9ec647a2caef1b56f50f3dd830f.pdf
38. Esl Gaming Gmbh. The Ultimate Counter-Strike Competition: Game Specific Rules. 2024. https://pro.eslgaming.com/tour/cs/#rules. Accessed 16 Jun 2024.
39. Riot Games. Valorant College: 2022–2023 College VALORANT Season Official Rules. 2022. https://rsaa.riotgames.com/wp-content/uploads/2022/09/2022-2023-College-VALORANT-Season-Official-Rules.pdf. Accessed 16 Apr 2024.
40. Noraxon. Ultium EMG. 2024. https://www.noraxon.com/our-products/ultium-emg/. Accessed 16 Nov 2024.
41. Mogk JPM, Keir PJ. Crosstalk in surface electromyography of the proximal forearm during gripping tasks. J Electromyogr Kinesiol. 2003;13:63–71. https://doi.org/10.1016/S1050-6411(02)00071-8.
42. Luttmann A, Jäger M, Laurig W. Electromyographical indication of muscular fatigue in occupational field studies. Int J Ind Ergon. 2000;25:645–60. https://doi.org/10.1016/S0169-8141(99)00053-0.
43. Besomi M, Hodges PW, Clancy EA, van Dieën J, Hug F, Lowery M, et al. Consensus for experimental design in electromyography (CEDE) project: amplitude normalization matrix. J Electromyogr Kinesiol. 2020;53:102438. https://doi.org/10.1016/j.jelekin.2020.102438.
44. Dahlqvist C, Nordander C, Granqvist L, Forsman M, Hansson G-Å. Comparing two methods to record maximal voluntary contractions and different electrode positions in recordings of forearm extensor muscle activity: refining risk assessments for work-related wrist disorders. Work. 2018;59:231–42. https://doi.org/10.3233/WOR-172668.
45. McGee C, Ho K. Tendinopathies in video gaming and esports. Front Sports Act Living. 2021;3:689371. https://doi.org/10.3389/fspor.2021.689371.
46. Unser M. Splines: a perfect fit for signal and image processing. IEEE Signal Process Mag. 1999;16:22–38. https://doi.org/10.1109/79.799930.
47. Qualisys Track Manager. Qualisys; 2020.
48. Qualisys, Qualisys Sports Marker Set Webinar. 2020. https://www.qualisys.com/webinars/qualisys-webinar-about-sports-marker-set/. Accessed 16 Dec 2024.
49. de Luca CJ. Myoelectrical manifestations of localized muscular fatigue in humans. Crit Rev Biomed Eng. 1984;11:251–79.
50. Dufaug A, Barthod C, Goujon L, Marechal L. New joint analysis of electromyography spectrum and amplitude-based methods towards real-time muscular fatigue evaluation during a simulated surgical procedure: A pilot analysis on the statistical significance. Med Eng Phys. 2020;79:1–9. https://doi.org/10.1016/j.medengphy.2020.01.017.
51. Institut für Arbeitschutz der Deutschen Gesetzkichen Unfallversicherung. Bewertung physischer belastungen Gemäß DGUV-Information 208 – 033 (bisher: BGI/GUV-I 7011) (Anhang 3). 2015. https://www.dguv.de/medien/ifa/de/fac/ergonomie/pdf/bewertung_physischer_belastungen.pdf
52. R Core Team. R: A Language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2024.
53. Peter K. Dunn. Scientific Research and Methodology: An introduction to quantitative research in science and health.; 2021.
54. Wilcox RR. Introduction to robust Estimation and hypothesis. Testing: Academic; 2021.
55. Blanca MJ, Arnau J, García-Castro FJ, Alarcón R, Bono R. Non-normal data in repeated measures ANOVA: impact on type I error and power. Psicothema. 2023;35:21–9. https://doi.org/10.7334/psicothema2022.292.
56. Field A. In: Angeles L, editor. Discovering statistics using IBM SPSS statistics. 5 ed. London, New Delhi, Singapore, Washington DC, Melbourne: SAGE; 2018.
57. Cohen J. Statistical Power Analysis for the Behavioral Sciences (2nd Edition). 2nd ed. Hillsdale, NJ: Erlbaum; 1988.
58. Lin M-I, Liang H-W, Lin K-H, Hwang Y-H. Electromyographical assessment on muscular fatigue–an elaboration upon repetitive typing activity. J Electromyogr Kinesiol. 2004;14:661–9. https://doi.org/10.1016/j.jelekin.2004.03.004.
59. Cifrek M, Medved V, Tonković S, Ostojić S. Surface EMG based muscle fatigue evaluation in biomechanics. Clin Biomech (Bristol). 2009;24:327–40. https://doi.org/10.1016/j.clinbiomech.2009.01.010.
60. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. J Physiol. 2008;586:11–23. https://doi.org/10.1113/jphysiol.2007.139477.
61. Kadefors R, Forsman M, Zoéga B, Herberts P. Recruitment of low threshold motor-units in the trapezius muscle in different static arm positions. Ergonomics. 1999;42:359–75. https://doi.org/10.1080/001401399185711.
62. Blazevich AJ, Babault N. Post-activation potentiation versus Post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. Front Physiol. 2019;10:1359. https://doi.org/10.3389/fphys.2019.01359.
63. Bawa P, Murnaghan C. Motor unit rotation in a variety of human muscles. J Neurophysiol. 2009;102:2265–72. https://doi.org/10.1152/jn.00278.2009.
64. Bawa P, Pang MY, Olesen KA, Calancie B. Rotation of motoneurons during prolonged isometric contractions in humans. J Neurophysiol. 2006;96:1135–40. https://doi.org/10.1152/jn.01063.2005.
65. Merletti R, Farina D, editors. Surface electromyography: physiology, engineering and applications. Hoboken, NJ: IEEE; Wiley;; 2016.
66. Chandrasekaran B, Pesola AJ, Rao CR, Arumugam A. Does breaking up prolonged sitting improve cognitive functions in sedentary adults? A mapping review and hypothesis formulation on the potential physiological mechanisms. BMC Musculoskelet Disord. 2021;22:274. https://doi.org/10.1186/s12891-021-04136-5.
67. Chrismas BCR, Taylor L, Cherif A, Sayegh S, Bailey DP. Breaking up prolonged sitting with moderate-intensity walking improves attention and executive

function in Qatari females. PLoS ONE. 2019;14:e0219565. https://doi.org/10.1371/journal.pone.0219565.

68. DiFrancisco-Donoghue J, Jenny SE, Douris PC, Ahmad S, Yuen K, Hassan T, et al. Breaking up prolonged sitting with a 6 min walk improves executive function in women and men esports players: a randomised trial. BMJ Open Sport Exerc Med. 2021;7:e001118. https://doi.org/10.1136/bmjsem-2021-001118.
69. Manci E, Theobald P, Toth A, Campbell M, DiFrancisco-Donoghue J, Gebel A, et al. It's about timing: how density can benefit future research on the optimal dosage of acute physical exercise breaks in esports. BMJ Open Sport Exerc Med. 2024;10:e002243. https://doi.org/10.1136/bmjsem-2024-002243.

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