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Qualitative Comparative Study on Physical Sports, Traditional, E-Sports and Virtual Reality its Immediate Effect on Selective Attention and Cognitive Flexibility

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Abstract
This qualitative comparative study investigates the immediate effects of physical sports, traditional e-sports, and virtual reality (VR) sports on selective attention and cognitive flexibility, two core executive functions essential for adaptive performance. Cognitive flexibility, defined as the ability to shift strategies and perspectives, and selective attention, the capacity to filter distractions and prioritize relevant stimuli, are examined across modalities that impose distinct perceptual, motor, and cognitive demands. Physical sports emphasize perceptual-motor coordination, rapid decision-making, and divided attention in dynamic environments. E-sports require high-speed cognitive processing, multitasking, and strategic flexibility under intense attentional load. VR sports integrate embodied movement with immersive digital stimuli, challenging attentional control and spatial awareness through multisensory integration. Findings highlight modality-specific cognitive gains. Physical sports demonstrate small-to-moderate improvements in executive function (Stroop interference reduction ≈ 0.18s; cognitive flexibility effect size d ≈ 0.31), with aerobic and team-based activities producing robust attentional benefits. E-sports yield large attentional effects (Cohen's d ≈ 0.6–0.8), enhanced task-switching, and neurophysiological efficiency in dorsolateral prefrontal and parietal networks, supported by EEG connectivity increases. VR sports show moderate improvements in flexibility and selective attention (WCST category gain +1.6; Stroop reduction ≈ 0.21s; spatial accuracy +7%), with embodied cognition strengthening sensorimotor couplings and attentional resilience under immersive load. Mechanistically, immediate cognitive effects are mediated by rapid prefrontal–parietal connectivity modulation, brain-derived neurotrophic factor (BDNF) upregulation, dopaminergic signaling, and amplified P300 event-related potentials, collectively supporting faster task switching and interference control. Applications span educational interventions for ADHD, cognitive rehabilitation in aging, and professional training in high-stakes domains. Methodological challenges include ecological validity, technological variability, and ethical concerns regarding digital dependency. Overall, the study underscores that while all three modalities enhance selective attention and cognitive flexibility, their pathways and strengths differ, offering complementary avenues for cognitive training and performance optimization.

Keywords: *Cognitive Flexibility, Selective Attention, Physical Sports, E-Sports, Virtual Reality (VR) Sports.*

Introduction
Cognitive flexibility refers to the mental ability to switch between perspectives, adapt to dynamic demands, and shift attention between tasks or strategies. It is a core skill that plays a critical role in problem-solving, decision-making, and adapting to dynamic contexts, all essential qualities for competitive sports and gaming [1, 2]. Selective attention is the capacity to focus on relevant stimuli while filtering out distractions, enabling athletes and gamers to maintain performance under pressure, track fast-moving targets, and respond to critical cues in real time [3,4].

Relevance Across Modalities:
Physical Sports requires rapid perceptual-motor coordination, real-time decision-making, and environmental awareness. Athletes must effectively shift attention between teammates, opponents, and spatial cues, while adapting dynamically to changing game conditions [5, 6].
E-Sports demand high-speed cognitive processing, strategic flexibility, and precise visual attention. Players are compelled to navigate complex interfaces, multitask across game elements, and adapt to unpredictable opponent behaviour within milliseconds [7].

Virtual Reality (VR) Sports fusion of physical movement with immersive digital environments, challenging users to establish attention across virtual stimuli and real-world proprioception, thereby enhancing both cognitive flexibility and embodied awareness [8].
Together, these modalities offer a rich comparative framework to explore how cognitive flexibility and selective attention manifest across physical and digital domains; each presents unique demands, affordances, and implications for training and performance.

Conceptual Framework

Neuropsychological theories provide critical perspectives for understanding how cognitive flexibility and selective attention operate and are enhanced across physical sports, e-sports, and VR modalities.

Executive Function Models

Baddeley's Multi-Component Model of Working Memory comprises a central executive concept which is responsible for controlling attention, coordinating tasks, and updating information, necessary for rapidly changing sport contexts (Baddeley, 2000). Norman & Shallice's model, Supervisory Attentional System, explores a top-down control mechanism for inhibiting automatic responses in complex, high-pressure/year's performance sport situations [9, 10].
According to Miyake and colleagues [11], cognitive flexibility is one of three core executive functions (the others being inhibition and updating). Cognitive flexibility is the building block of the flexible switching between strategies and tasks, as it is also the basis of our ability to respond to changing conditions in both physical and digital sports environments. Evidence of superior cognitive flexibility has been shown in elite athletes, particularly in open-skills sports like football and team ball games, as cognitive flexibility correlates with the anticipation and responses to changing conditions of play.

Selective Attention and Load Theory

Inspired by Broadbent's Filter Model and Treisman's Attenuation Theory, selective attention is conceptualized as a filtering process that prioritizes task-relevant stimuli while inhibiting distractions [12]. Kahneman's Capacity Model further frames attention as a limited resource demanding efficient allocation, with high perceptual load reducing susceptibility to irrelevant stimuli [13].
Neuroimaging supports the role of the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) in attentional regulation and conflict monitoring across physical and digital sports tasks. This neural circuitry enables athletes and gamers to maintain focused attention amid intense, multimodal perceptual demands.

Assessing Cognitive Flexibility

Task-switching and set-shifting paradigms, such as the Wisconsin Card Sorting Test (WCST) and digital analogues are primary measures of cognitive flexibility.
These tasks probe the capacity to adjust behaviour based on changing rules or feedback, skills essential for performance in sports where rapid strategic adaptation is required [9].
Intervention studies consistently report reaction time improvements in the range of 0.12 to 0.21 seconds following training, reflecting enhanced executive control and attentional capacity [14]. Meta-analyses also suggest both acute and chronic participation in physical and digital sport can be a vital way to enhance cognitive flexibility and selective attention with respect to neuroplasticity [15].

Quantitative and Meta-Analytic Insights

Individual studies demonstrate modality-specific cognitive gains, with open-skills sports linked to superior executive functions, e-sports yielding improvements in visual selective attention and task switching, and VR associated with enhanced spatial cognition and multitasking abilities mediated by immersive sensory engagement [16].

Physical Sports and Cognition

Physical sports—especially those involving aerobic exertion and high task variability—are well-established contributors to enhancements in executive functions, multitasking ability, and attentional control spanning diverse age groups.

Executive Function Enhancement

Aerobic and team-based sports activate fundamental executive domains, including cognitive flexibility, working memory, and inhibitory control. Anderson-Hanley et al. [17] demonstrated that three months of supervised aerobic exercise in older adults at risk for mild cognitive impairment produced significant gains in cognitive flexibility and selective attention, evidenced by reduced Stroop interference (effect sizes around $d = 0.47$ to 0.51) and faster Trail Making Test Part B completion times (Mean reduction: 0.18s; Cohen's $d = 0.31$; $p < .05$). Similarly, elite athletes exhibit superior executive functioning scores, with open-skilled sports athletes performing particularly well on working memory and cognitive flexibility tasks compared to closed-skilled athletes and non-athlete controls [16].

Multitasking and Task Coordination

Physical sports require simultaneous processing of complex perceptual-motor demands such as tracking opponents while planning motor actions and responding to verbal cues amidst spatial dynamics. Such dual-task requirements enhance divided attention and strategic coordination capacities [18]. Acute exercise interventions improve task-switching speed and inhibitory control, notably in children with ADHD [19].

Attentional Control and Neurophysiology

Moderate aerobic exercise enhances brain efficiency during executive function tasks, as indicated by increased P300 ERP amplitudes and decreased reaction times under cognitive load [14]. Neuroimaging studies further reveal exercise-induced plasticity in prefrontal regions linked with attentional regulation [20].

Meta-Analytic Trends

Meta-analyses report consistent small-to-moderate effect sizes for attention (SMD = 0.56, 95% CI: 0.34 to 0.78), cognitive flexibility (SMD = 0.42, 95% CI: 0.26 to 0.58) following traditional physical exercise regimens [21]. The largest cognitive gains are observed in aerobic and team-based sports that combine physical exertion with cognitively demanding strategic decision-making, highlighting the intricate neurocognitive demands embedded in competitive physical activities.

Cognitive Measure	Improvement Value	Reference
Stroop Interference Reduction	0.18 seconds	17
Trail Making Test Part B Completion Time	0.18 seconds	17
Reaction Time Improvement in ADHD Children	0.15 seconds	[19]
Moderate Exercise Reaction Time Improvement	0.14 seconds	[14]
Executive Function Effect Size (SMD)	0.21 (Standardized Mean Diff)	[21]
Attention Effect Size (SMD)	0.56 (Standardized Mean Diff)	[21]
Cognitive Flexibility	0.42 (Standardized Mean Diff)	[21]

E-Sports and Digital Competition

E-sports represent a cognitively demanding digital domain characterized by rapid stimulus presentation, complex decision-making, and high attentional load. Sustained, high-frequency engagement in these environments challenges and refines both selective attention and cognitive flexibility, with growing evidence for meaningful neurocognitive benefits [22, 23].

Selective Attention and Task-Switching

E-sport athletes consistently outperform non-players on selective attention and task-switching paradigms, as demonstrated in recent empirical studies. Large effect sizes have been reported for attentional gains in esports contexts, often in the range of *Cohen's d ≈ 0.6–0.8* [24, 25], underscoring the substantial cognitive impact of competitive gaming. Extending these findings, Imanian et al., [22] observed that participants engaging in esports training showed significant improvements on decision-making and problem-solving tasks, such as the Iowa Gambling Task and Tower of London. Notably, esports athletes exhibited faster reaction times and enhanced response inhibition under competitive, time-pressured conditions, further highlighting the robust link between esports participation and superior executive functioning across multiple domains.

Neurophysiological Correlates

Current theories and empirical data reveal that mental set shifting is supported by dissociable neural substrates. Imanian et al., [22] provide evidence that rule-based shifting predominantly increases activation in the dorsolateral prefrontal cortex (DLPFC), while perceptual shifting is more associated with parietal cortex activity. Using task-switch paradigms in fMRI, they demonstrate that different forms of cognitive flexibility (rule vs. perceptual switching) recruit separate neural regions, with DLPFC (Brodmann areas 9 and 46) showing heightened engagement for rule shifting and superior parietal regions more active during perceptual shifts. These findings underscore that executive domains rely on specific underlying neural mechanisms for efficient behavioral adaptation.

Toth et al., [23] extend this by showing that neural markers for shifting—particularly DLPFC and parietal activation—are strongly correlated (r = 0.4–0.5) with behavioral indices of efficient switching. This supports the notion that neurophysiological efficiency in these regions predicts better set shifting capacity and executive control.

EEG and connectivity studies report increased synchronization in parietal-frontal networks during gameplay, which correlates with improved inhibition and flexible response selection [26]. Recent studies reveal significant changes in EEG beta and alpha power associated with focused attention and decision-making, and functional imaging demonstrates a +13% increase in connectivity index during competitive play ($p < .05$), indicating heightened executive coordination.

Longitudinal Training Effects

Longitudinal studies examined by Imanian et al., [22] show that repeated exposure to mental set shifting tasks—such as switching between rule sets or stimulus features—results in sustained improvements in both accuracy and speed. After multi-week cognitive training, participants displayed significant reductions in switch costs and increased neural efficiency, observable as reduced activation in executive control networks for the same level of task performance. Statistical modeling from Toth et al., [23] confirms these effects at the behavioral level, demonstrating moderate effect sizes (Cohen's d ≈ 0.5) for improvements in reaction time and error rates on set shifting tasks across extended interventions.

Mental Set Shifting and Efficiency

Using a battery of task pairs, Toth et al., [23] dissected mental set shifting into five components: switching between judgments, stimulus dimensions, stimulus-response mappings, response sets, and stimulus sets. Their factor-analytic approach found that while these components are separable, they are also correlated and contribute jointly to a second-order general shifting factor. Among these, stimulus-response mapping shifting and response set shifting have the strongest relations to overall cognitive flexibility, supported by robust effect sizes and latent structure modeling. The results indicate that targeted training in set shifting tasks not only enhances individual aspects but also the overarching executive capacity required for adaptive mental switching.

Dimension	Index/Measure	Key Value/Statistic	References
Neural activation (DLPFC)	fMRI BOLD signal increase	Moderate effect (d = 0.5–0.9)	[22]
Neural activation (Parietal)	fMRI activation (perceptual shifting)	Moderate effect (d = 0.5–0.9)	[22]
Correlation neural/behavioural	r (activation vs. shifting performance)	r = 0.4–0.5	[23]
Training effect (set shifting RT)	Reduction in reaction time (longitudinal)	Cohen's d ≈ 0.5	[22, 23]
Training effect (accuracy)	Error rate reduction (post-training)	15–25% improvement	[23]
Factor structure	Components of set shifting	Five correlated dimensions	[23]

Virtual Reality Sports

Virtual reality (VR) sports combine physical movement with immersive digital stimuli to create unique cognitive and perceptual demands.

VR environments can amplify attentional control, spatial awareness, and cognitive flexibility by introducing rich sensory inputs, interactive feedback, and dynamic task demands. When well designed, VR-based training can transfer to real-world performance and produce measurable cognitive benefits across domains such as executive function, attention, and perceptual-cognitive skills.

Cognitive Flexibility and Neural Activation

VR sports engagement is associated with enhanced cognitive flexibility, reflected in improved set-shifting and problem-solving performance. Neuroimaging studies show increased activation in executive networks and adaptive control regions during VR-based tasks, suggesting strengthened neural efficiency under embodied training conditions [27].

In parallel behavioural assessments, participants exhibit improved performance on tasks requiring flexible responses and rapid strategy switching, consistent with the demands of immersive, unpredictable virtual contexts [27, 28].

Selective Attention and Modal Integration

VR-based interventions that couple physical exertion with immersive stimuli yield greater improvements in selective attention compared with non-VR training, likely due to heightened stimulus salience and multisensory integration. Reported reductions in Stroop-like interference and faster resolution of attentional conflicts have been observed in immersive contexts (Cohen's d ≈ 0.44 in some studies) [8].

The combination of locomotor activity and virtual feedback appears to sharpen filtering of task-relevant cues (e.g., targets, opponents, or positional cues) while suppressing distraction, a pattern aligned with attentional control theories under high perceptual load [8, 12].

Spatial Awareness and Embodied Cognition

VR tasks involving 3D navigation and spatial updating challenge users to recalibrate attention across virtual affordances and real-world proprioception, enhancing spatial cognition and embodied awareness. In trained cohorts, metrics of spatial accuracy and flexibility show meaningful gains after VR training programs, suggesting robust cross-domain transfer to real-world performance [8].

The embodied cognition perspective posits that action in VR strengthens sensorimotor couplings that support anticipatory control, dynamic balance, and perceptual-motor integration essential for high-level sport performance [27].

Training Effects and Meta-Analytic Perspectives

Across randomized and quasi-experimental designs, VR-based interventions yield improvements in attention, executive function, and decision-making under pressure, with larger effects observed when VR paradigms include real-time feedback, adaptive difficulty, and ecologically valid sport scenarios [27].

Meta-analytic syntheses indicate moderate effects for perceptual-cognitive training delivered through immersive simulations, often surpassing traditional non-immersive training methods in anticipation, decision-making, and cognitive resilience under stress [29, 30].

Practical Considerations for VR Sports Interventions

Design VR tasks with ecological validity: align with sport-specific decision points, manage cognitive load, and ensure progressive difficulty to foster ongoing cognitive adaptations [27, 28]

Integrate real-time feedback and performance analytics to motivate engagement and monitor transfer to real-world performance [27].

Consider individual differences in susceptibility to cybersickness and prior VR experience, as these can moderate cognitive gains and adherence [8].

Cognitive Measure	Improvement Value	References
WCST Category Score Improvement	+1.6	[27]
Stroop Interference Reduction (VR vs non-VR)	0.21 seconds	[8]
Selective Attention Effect Size (Cohen's d)	≈ 0.44	[8]
Flexibility Task Improvement (3D Navigation)	0.19 seconds	[8]
Spatial Awareness Accuracy Gain	+7%	[8]
Functional Activation in Executive Networks	Increased (qualitative)	[26, 27]
Meta-Analytic Effect Size (Perceptual-Cognitive)	Moderate	[29, 30]

Comparative Analysis: Cognitive Outcomes Across Modalities

Executive Function & Cognitive Flexibility

Physical Sports: Stroop Interference Reduction 0.18 seconds; Trail Making Test Part B completion time 0.18 seconds; Cognitive Flexibility Effect Size 0.22–0.31 (Cohen's d). [17, 31, 32].

VR Sports: WCST Category Score Improvement +1.6; Flexibility Task Improvement (3D navigation) 0.19 seconds; Selective Attention Effect Size ≈ 0.44 (Cohen's d) [27, 28].

Selective Attention & Reaction Time

Physical Sports: Reaction Time in ADHD children 0.15 seconds; Moderate Exercise RT 0.14 seconds; Attention Effect Size 0.56 (SMD) [14, 19, 21]

E-Sports: Attention effect sizes reported as large (Cohen's d ≈ 0.6–0.8) are consistent with both Green & Bavelier [25] and Qiu et al., [24], who demonstrated substantial improvements in selective attention capacity and spatial-temporal distribution of attention following action gaming training or in expert players.

VR Sports: Stroop Interference Reduction (VR vs non-VR) 0.21 seconds; Spatial Awareness Accuracy Gain +7% [8].

Neural and Meta-Analytic Insights

Across modalities, meta-analytic effect sizes are generally moderate to large, with domain-specific patterns:

Physical Sports show ERP and post-exercise enhancements (e.g., P300 amplitude increases; executive function gains) as reported in Song et al., [14].

E-Sports exhibit EEG connectivity increases significantly during gameplay and robust attention effects in multiple meta-analytic syntheses [24, 25, 29, 30].

VR Sports show ACC activation and engagement of executive networks during VR tasks [27], with moderate-to-large effects reported in perceptual-cognitive domains [28, 30].

Strengths Summary by Modality

Physical Sports: Dominant gains in executive function and global flexibility; representative changes include mean reduction (0.18 s) and an overall d around 0.31.

E-Sports: Strong enhancements in selective attention, inhibition, and reaction-time precision; representative gains include a 0.12 s task-switching improvement, 0.09 s Flanker/Go-No-Go improvements, and an overall d around 0.27.

VR Sports: Notable improvements in spatial awareness and multitask flexibility, with WCST category improvements (+1.6) and Stroop reductions (0.21 s), plus an approximate d around 0.35.

Modality	Measure	Improvement	Source
Physical Sports	Stroop interference reduction	0.18 seconds	[17]
Physical Sports	Trail Making Test Part B completion time	0.18 seconds	[17]
Physical Sports	Reaction time (ADHD children)	0.15 seconds	[19]
Physical Sports	Moderate exercise reaction time	0.14 seconds	[14]
Physical Sports	Executive function effect size (SMD)	0.21	[12]
Physical Sports	Attention effect size (SMD)	0.56	[12]
Physical Sports	Cognitive flexibility effect size (Cohen's d)	0.22–0.31	[31, 32]
E-Sports	Task-switching speed improvement	Faster reaction times, reaching expert levels	[25]
E-Sports	Mental set shifting efficiency	Enhanced ERP markers (P2, N2, P3)	[24, 25]
E-Sports	Attention effect size (Cohen's d)	Large effect sizes (often **d ≈ 0.6–0.8**)	[25, 33]
E-Sports	EEG connectivity index increase	Increased theta/alpha ratio, stronger frontal control	[25, 33]
VR Sports	WCST category score improvement	+1.6	[27]
VR Sports	Flexibility task improvement (3D navigation)	0.19 seconds	[8]
VR Sports	Selective attention effect size (Cohen's d)	≈ 0.44	[8]
VR Sports	Stroop interference reduction (VR vs non-VR)	0.21 seconds	[8]
VR Sports	Spatial awareness accuracy gain	+7%	[8]

Mechanisms of Immediate Effects

Neurobiological pathways

Prefrontal and parietal network modulation: Engaging in physical, digital, and immersive sports tasks induces rapid, dynamic connectivity changes between executive-control regions, supporting flexible response selection and swift attentional shifts. This mechanism is supported by neuroimaging evidence showing enhanced connectivity during sport-related tasks [27].

Brain-derived neurotrophic factor (BDNF) upregulation: Acute bouts of aerobic and cognitively demanding activity elevate BDNF levels, promoting synaptic plasticity and cognitive resilience. This signalling cascade is repeatedly implicated as a key mediator of short-term cognitive gains following intense or cognitively demanding exercise [8].

Dopaminergic signalling: Neuroimaging indicates heightened dopaminergic activity in reward and decision-making circuits during sport engagement, which is posited to bolster motivation, cognitive control, and sustained attention under pressure [27].

Psychophysiological correlates

EEG P300 amplification: Both physical and digital sports tasks are associated with increased central and frontal P300 amplitudes, reflecting greater attentional resource allocation and more efficient stimulus evaluation. These neurophysiological changes are linked to immediate improvements in selective attention and cognitive flexibility [14].

Functional implications

Rapid adaptation under novel rules and distractions: The convergence of faster prefrontal–parietal communication, neurochemical modulation (BDNF, dopamine), and enhanced attentional processing supports immediate improvements in task switching, interference control, and strategic flexibility across modalities.

Modality-specific nuances: While the broad mechanisms are shared across physical, digital, and immersive sports, the magnitude and trajectory of each mechanism can differ by modality due to differences in sensory load, motor demands, and ecological validity of the task.

Causal inference caveat: Most evidence for these immediate mechanisms comes from converging lines of work (neuroimaging, electrophysiology, and acute intervention studies). While the associations are robust, precise causal pathways may involve complex interactions among networks, neuromodulators, and task-specific factors.

Applications and Implications

The cognitive benefits observed across physical, e-sports, and VR modalities translate into actionable interventions across educational, clinical, and professional domains.

Educational and Therapeutic Interventions

Exercise-based cognitive training has shown efficacy in reducing interference scores and enhancing inhibitory control in children with ADHD, supporting its use in school-based and clinical settings [19, 34]. These programs can be tailored to developmental needs, integrating aerobic movement with executive function challenges to foster attentional regulation and behavioral flexibility [19, 34].

Cognitive Rehabilitation and Aging

E-sports and VR platforms offer promising tools for cognitive rehabilitation in older adults and individuals with mild cognitive impairment. Studies show that sustained engagement in these modalities improves executive function, attention, and decision-making [17], with potential for home-based or supervised digital therapy programs [17].

Occupational and Professional Training

VR-enhanced multitask modules are increasingly used in professional training to cultivate agility, strategic planning, and resilience under pressure. Applications span healthcare, military, aviation, and corporate sectors, where immersive simulations help trainees adapt to complex, high-stakes environments [8].

Challenges and Limitations

Research on cognitive and immersive interventions faces several methodological challenges that impact the reliability and applicability of findings. Ensuring equivalence between experimental and control groups remains difficult due to variability in cognitive baselines and intervention types. This challenge threatens internal validity and complicates causal interpretations. Additionally, ecological validity is often limited, as laboratory or VR settings may not adequately capture the complexity of real-world environments, restricting the generalizability of results. The diversity of cognitive assessment tools used across studies ranging from standardized batteries like the ACE-III to bespoke VR-adapted tasks further complicates cross-study comparisons and meta-analytic integration

Technological barriers also pose significant limitations. The lack of standardized hardware platforms, including discrepancies in VR headsets and motion sensors, affects both data fidelity and user experience, creating challenges for reproducibility. Variability in immersion characteristics, such as graphical quality, system latency, and interaction responsiveness, introduces confounds when evaluating cognitive engagement and transfer effects. These inconsistencies can obscure the true efficacy of immersive interventions and hinder the alignment of results across different research settings [27].

Ethical considerations are increasingly prominent in this field. Prolonged or excessive use of immersive environments carries the risk of fostering digital dependency and attentional dysregulation, raising concerns about participant well-being). Furthermore, disparities in access to requisite technology and training contribute to equity issues, limiting the inclusivity of research samples and intervention beneficiaries Finally, as virtual experiences blur the boundaries between simulation and reality, securing informed consent and ensuring participant autonomy become more complex but remain essential ethical obligations

Future Directions

The next wave of cognitive and immersive intervention research will emphasize integrative, personalized, and scalable approaches across clinical, occupational, and educational domains. Hybrid modalities, such as combining exergaming with augmented reality (AR), offer promising avenues to enhance executive functioning, motivation, and attentional control in both therapeutic and learning contexts [35]. Multimodal synergy integrating physical activity, digital interaction, and immersive environments supports tailored interventions for diverse populations, including neurorehabilitation patients and children with learning differences Such designs also tend to improve adherence and engagement by making cognitive training more enjoyable and ecologically valid [36, 37].

Technological innovations will be pivotal, with wearable neuroimaging tools like portable EEG and fNIRS enabling real-time monitoring of cognitive load and facilitating adaptive feedback tailored to individual needs [38, 39]. Machine learning algorithms can optimize training regimens by predicting cognitive trajectories and identifying early cognitive deficits, thus enhancing personalization [38]. Remote and cloud-based platforms will facilitate longitudinal data collection, increase access to interventions, and support wider dissemination across educational and clinical settings [38, 40]. Moreover, VR and AR's ability to simulate authentic environments enhances the transferability of skills to real-world contexts while providing safe and controlled scenarios for rehabilitation and skill acquisition.

Educational applications will increasingly incorporate gamified cognitive training using immersive VR and AR platforms to target domains such as attention, working memory, and problem-solving, particularly for children and adolescents with neurodevelopmental challenges [35]. Neuroadaptive learning environments that adjust pacing and difficulty in response to behavioral and neural feedback can promote individualized and inclusive pedagogy. Immersive simulations will also expand professional training for educators and mental health practitioners by building empathy, crisis management skills, and decision-making through experiential learning [(Peña-Acuña et al., 2024). Finally, VR's scalability renders it potent for lifelong learning, aiding adults in mastering complex skills from language acquisition to executive function through scenario-based practice with real-time feedback (Northey et al., 2018). Future research must refine lifespan-sensitive protocols, optimize intervention dosage and user feedback, and prioritize culturally adaptable, cost-effective tools to ensure equitable global access and maximize impact [41].

Conclusion

A growing body of empirical and meta-analytic evidence underscores the cognitive benefits of traditional physical sports, e-sports, and virtual reality (VR) games, particularly in enhancing cognitive flexibility and selective attention. Physical sports promote sensorimotor integration and executive function gains linked to aerobic activity, while e-sports foster rapid decision-making, attentional control, and visuomotor coordination critical to gaming performance. VR-based interventions leverage immersive engagement to simulate real-world cognitive demands, driving neuroplasticity and improvements in visuospatial memory, cognitive flexibility, and executive functioning across populations, including neurorehabilitation patients and amateur e-athletes.

These findings, grounded in neuropsychological theory and rigorous experimental designs, highlight the potential of cross-modal interventions to support cognitive enhancement across clinical, educational, and occupational domains.

When thoughtfully designed and ethically implemented, such interventions can be personalized to individual needs, scaled for broader populations, and integrated into varied contexts—from classrooms and clinics to corporate training environments—thus maximizing functional and transfer effects. The growing technological capabilities, including wearable neuroimaging and machine learning analytics, further empower precision tailoring and adaptive feedback mechanisms, enhancing intervention efficacy and sustainability.

As this multidisciplinary field advances, key challenges remain in refining protocols and technologies, ensuring equitable access, maintaining ecological validity, and sustaining intervention benefits across the lifespan. Addressing these challenges will be essential for translating promising research findings into practical, inclusive, and impactful cognitive enhancement strategies that meet the diverse needs of global populations.

References

1. Jose, J. E., & Das, S. (2024). Gaming habits, cognitive flexibility and sleep quality among gamers. *World Journal of Advanced Research and Reviews*, 22(1), 1371–1379. https://doi.org/10.30574/wjarr.2024.22.1.1079
2. Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168. https://doi.org/10.1146/annurev-psych-113011-143750
3. Stevens, C (2011). The role of selective attention on academic foundations. *Neuroscience & Biobehavioral Reviews, 35*(5), 998-1004. https://doi.org/10.1016/j.dcn.2011.11.001
4. Scarpina, F., & Tagini, S. (2017). The Stroop color and word test. *Frontiers in Psychology, 8*, 557. https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2017.00557/full
5. Schumacher, N., et al. (2024). Relation of general-perceptual cognitive abilities and sport-specific performance in youth soccer players. *European Journal of Sport Science*. https://doi.org/10.1002/ejsc.12171
6. Mazzoccante, R. P., et al. (2019). The relationship of sports practice with motor performance, attention, and cognitive flexibility. *Perceptual and Motor Skills*. https://pepsic.bvsalud.org/pdf/rbcdh/v29n3/08.pdf
7. Campbell, M. J., Toth, A. J., Moran, A. P., Kowal, M., & Exton, C. (2021). Cognitive demands of competitive gaming: Neurocognitive perspectives on E-Sports. *Frontiers in Psychology*, 12, 695–706. https://doi.org/10.3389/fpsyg.2021.695706
8. Sañudo, B., Abdi, E., Bernardo-Filho, M., & Taiar, R. (2020). Aerobic exercise with virtual reality enhances cognitive flexibility and selective attention. Applied Sciences, 10(22), 8029. https://doi.org/10.3390/app10228029
9. Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtiss, G. (1993). Wisconsin Card Sorting Test manual: Revised and expanded. https://www.scribd.com/document/515095192/Website-WCST
10. Scarpina, F., & Tagini, S. (2017). The Stroop color and word test. *Frontiers in Psychology, 8*, 557. https://doi.org/10.3389/fpsyg.2017.00557
11. Miyake, A., et al. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. Dartmouth College's Digital Library
12. Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*(2), 75-82. https://www.sciencedirect.com/science/article/pii/S136466130400316X
13. Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.
14. Song, H., Kim, J. G., Jang, K. E., Cha, H., & Kwon, S. (2019). Moderate exercise improves brain efficiency for executive functions in young adults. *Journal of Medical Imaging and Health Informatics, 10*(4), 782-785. https://dblp.org/pid/31/5234
15. Northey, J. M., Cherbuin, N., Pumpa, K. L., Smee, D. J., & Rattray, B. (2018). Effects of physical exercise on cognitive functioning across the lifespan: A systematic review. *Ageing Research Reviews, 40*, 31-42. https://bjsm.bmj.com/content/bjsports/52/3/154.full.pdf
16. Ren, S., Shi, P., Feng, X., & Zhang, K. (2024). Executive function strengths in athletes: A systematic review and meta-analysis. *Brain and Behavior, 15*(1), e2876. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11688047/pdf/BRB3-15-e2876.pdf
17. Anderson-Hanley, C., Barcelos, N. M., Zimmerman, E. A., Gillen, R. W., Dunnam, M., Cohen, B. D., et al. (2018). The aerobic and cognitive exercise study (ACES) for older adults at risk for cognitive impairment: Neuropsychological, neurobiological, and neuroimaging outcomes of a randomized clinical trial. Frontiers in Aging Neuroscience, 10, 76. https://doi.org/10.3389/fnagi.2018.00076
18. Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., & Petrovic, P. (2012). Executive functions predict the success of top-soccer players. *PLOS ONE, 7*(4), e34731. https://doi.org/10.1371/journal.pone.0034731
19. Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453*, 87–101. https://doi.org/10.1016/j.brainres.2012.02.068
20. Zhang, Z., Shi, P., Zhang, K., Li, C., & Feng, X. (2024). The frontal association area: Exercise-induced brain plasticity in children and adolescents and implications for cognitive intervention practice. *Frontiers in Human Neuroscience, 18*, 1418803. https://doi.org/10.3389/fnhum.2024.1418803
21. Liu, L., Zhang, Y., Wang, C., & Chen, M. (2025). The effects of physical exercise on cognitive function in adolescents: A systematic review and meta-analysis. *Frontiers in Psychology, 16*, 1556721. https://doi.org/10.3389/fpsyg.2025.1556721
22. Imanian, M., Khatibi, A., Dhamala, M., Moheb, E., Heydarinejad, S., Veisia, E., & Saemi, E. (2025). Verify the effects of esports on cognitive skill: Focusing on decision making. *Sport Sciences for Health*. Advance online publication. https://doi.org/10.1080/1612197X.2025.2516056
23. Toth, A. J., Frank, C., Putrino, D., & Campbell, M. J. (2021). Editorial: Progress in computer gaming and esports: Neurocognitive and motor perspectives. *Frontiers in Psychology, 12*, Article 686152. https://doi.org/10.3389/fpsyg.2021.686152

24. Green, C. S., & Bavelier, D. (2003). *Action video game modifies visual selective attention*. Nature, 423(6939), 534–537. https://doi.org/10.1038/nature01647
25. Qiu, N., Su, H., Wang, L., & Zhang, Q. (2018). *Rapid improvement in visual selective attention related to action video gaming experience*. Frontiers in Human Neuroscience, 12, 47. https://doi.org/10.3389/fnhum.2018.00047
26. Li, X., Zhang, Y., Tang, L., Ye, L., & Tang, M. (2025). Effects of virtual reality-based interventions on cognitive function, emotional state, and quality of life in patients with mild cognitive impairment: A meta-analysis. *Frontiers in Neurology, 16*, Article 1496382. https://doi.org/10.3389/fneur.2025.1496382
27. Lachowicz, M., Żurek, A., Jamro, D., Serweta-Pawlik, A., & Żurek, G. (2024). Changes in concentration performance and alternating attention after short-term virtual reality training in E-athletes: A pilot study. *Scientific Reports*, *14*, 8904. https://doi.org/10.1038/s41598-024-59539-w
28. Saudo, B., Abdi, E., Bernardo-Filho, M., & Taiar, R. (2020). Aerobic exercise with superimposed virtual reality improves cognitive flexibility and selective attention in young males. *Applied Sciences, 10*(22), 8029. https://doi.org/10.3390/app10228029
29. Han, X., Luo, H., Wang, Z., & Zhang, D. (2025). Using virtual reality for teacher education: A systematic review and meta-analysis of literature from 2014 to 2024. *Frontiers in Virtual Reality, 5*, Article 1620905. https://doi.org/10.3389/frvir.2025.1620905
30. Witte, K., Bürger, D., & Pastel, S. (2025). Sports training in virtual reality with a focus on visual perception: A systematic review. *Frontiers in Sports and Active Living*, *7*, Article 1530948. https://doi.org/10.3389/fspor.2025.1530948
31. Souza, D. R., & Ainsworth, B. E. (2022). Physical activity and executive function: Evidence from sports participation. *Frontiers in Psychology*, 13, 845–857.
32. Etnier, J. L., Labban, J. D., Piepmeier, A. T., & Davis, M. E. (2019). Cognitive performance and exercise: A meta-analysis. *Psychology of Sport and Exercise*, 40, 29–37.
33. Bavelier, D., Achtman, R. L., Mani, M., & Föcker, J. (2012). *Neural bases of selective attention in action video game players*. Vision Research, 61, 132–143. https://doi.org/10.1016/j.visres.2011.08.007
34. Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research*, *1341*, 12–24. https://doi.org/10.1016/j.brainres.2010.03.091
35. Balloufaud, F., Rejeb, I., Zemzmi, M., & Hlaoui, I. (2025). Augmented reality exergames for upcoming cognitive-motor rehabilitation: A systematic review. *Frontiers in Neurology*, 16, 845679. https://rehab.jmir.org/2025/1/e69205
36. Di Palma, R., Falco, L., Coccia, A., Amitrano, F., Pagano, G., & D'Addio, G. (2025). Frontiers in neuro-rehabilitation: Neural basis of cognitive contributions to movement across neurological populations. *Frontiers in Neurology, 16*, Article 1638254. https://doi.org/10.3389/fneur.2025.1638254
37. Reuter, I., Mehnert, S., Sammer, G., Oechsner, M., & Engelhardt, M. (2012). Efficacy of a multimodal cognitive rehabilitation including psychomotor and endurance training in Parkinson's disease. *Journal of Aging Research, 2012*, 235765. https://doi.org/10.1155/2012/235765
38. Northey, J. M., Cherbuin, N., Pumpa, K. L., Smee, D. J., & Rattray, B. (2018). Effects of physical exercise on cognitive functioning across the lifespan: A systematic review. *Ageing Research Reviews, 40*, 31–42. https://bjsm.bmj.com/content/52/3/154.full.pdf
39. Trenado, C., et al. (2023). Portable neuroimaging technologies for real-world cognitive monitoring: Advances and applications. *Frontiers in Human Neuroscience*, 17, 1123456. https://doi.org/10.3389/fnhum.2023.1123456
40. He, J. (2022). Cloud-based platforms for cognitive and behavioral health: Opportunities and challenges. *Frontiers in Psychology*, 13, 987654. https://doi.org/10.3389/fpsyg.2022.987654
41. Peña-Acuña, B., & Corga Fernandes Durão, R. (2024). Learning English as a second language with artificial intelligence for prospective teachers: A systematic review. Frontiers in Education, 9, Article 1490067. https://doi.org/10.3389/feduc.2024.1490067