Digital Life

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Special Issue: Digital Technology in Sports and Physical Activity

Preface to the Special Issue

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At the dawn of the 21st century, we find ourselves at a pivotal moment when the trajectory of sport and physical activity is being dramatically reshaped by the relentless advance of digital technology. This special issue, titled "Digital Technology in Sport and Physical Activity," is intended as a beacon to guide through the exciting confluence of fields that were once considered distinct and disparate. Our goal is to illuminate the transformative effects of digital technologies across the sports spectrum, offering a comprehensive exploration of their impact on sports science, social science, life science, and information technology.

The eclectic collection of eight articles in this issue is a testament to the diverse and significant role that digital technology plays in the field of sport. These pieces not only provide a snapshot of current innovations, but also serve as a springboard for discussions about the future of sport and physical activity in a digitized world. From improving educational approaches in sports to fine-tuning athletic performance, ensuring safety, aiding recovery, and even reshaping the competitive landscape of esports, the range of topics covered is both vast and compelling.

This special issue acts as a catalyst, encouraging readers to question established norms, explore new possibilities, and innovate at the intersection of digital technology and sport. Areas of inquiry range from tangible improvements in athletic performance and education to subtler shifts in strategy, analytics, and the way sports are viewed and consumed. This diversity of content reflects the broad impact of digital technology on the field and challenges us to rethink what is possible when we harness the power of innovation in physical activity and sport.

As we unveil these articles, we invite a community of scholars, practitioners, and enthusiasts to join us on a journey of discovery and discussion. The future of sport and physical activity as seen through the lens of digital technology is not just about technological advancement; it is about the evolution of our understanding, our practices, and the very nature of sport itself. This special issue aims to inform, inspire and stimulate action, contributing to a future in which technology and physical activity merge in ways previously unimaginable.

Finally, our deepest gratitude goes to the authors whose groundbreaking research has made this issue possible, and to our readers whose passion and curiosity drive the field forward. As we embark on this exploration together, we anticipate that the journey through the pages of this special issue will not only enlighten, but also challenge and reward us all as we glimpse the promising horizon of sport and physical activity shaped by advances in digital technology. Here's to uncovering new knowledge, sparking innovation and embracing the endless possibilities that lie ahead in the ever-evolving landscape of digital technology in sport.

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Special Issue: Digital Technology in Sports and Physical Activity
Review Article (Invited)

Japanese elementary teachers' problem-based learning through online professional development on teaching Japanese language learners in physical education

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Abstract
Public schools in Japan have become increasingly linguistically, ethnically, culturally, and religiously diverse (Furuta et al., 2022). In rural regions, the number of Japanese-national students is declining in schools, and education services are shrinking (Mantanle, 2014) because of the aging population and low birth rate. This has led to serious economic concerns such as a smaller workforce and fewer taxpayers. This means that school districts in Japan will need new immigrant residents who can contribute to the sustainable future of education in Japan. However, in order to adequately serve this new population, Japanese teachers will need to receive training and demonstrate pedagogical knowledge and skills in relation to social justice and diversity, and facilitate inclusive and effective learning opportunities for all students.
Our research team conducted two exploratory studies focusing on (a) Japanese elementary school teachers' positioning in teaching physical education to Japanese language learners (Furuta et al., 2022) and (b) Japanese elementary classroom teachers' experiences with the involvement of immigrant parents regarding physical education (Tomura et al., 2024a). Based on the findings of these studies, our research team developed online professional development modules for teachers using a problem-solving approach as part of a project funded by the Japan Society for the Promotion of Science.

Keywords: Online Professional Development, Physical Education, Japanese Language Learners, Elementary Teachers.

1. Introduction

It is well known that many teachers are responsible for improving their practices through ongoing professional development (PD) throughout their careers (Avalos, 2011). Recently, online education formats became the central form of interaction not only between teachers and students (Murtagh et al., 2023) but also for teacher PD (Perry, 2023) around the world due to the COVID-19 pandemic. However, effective online education is not simply a matter of adapting the structure and modes of interaction of the face-to-face classroom environment to an online format (Sato & Haegele, 2018). Rather, cognitive expectations, instructional choices, and supportive practices need to be reconsidered in recognition of the complexity of issues (Peter, 2003). In physical education, MacPhail and Lawson (2020) and Luguetti et al. (2021) note that many teachers struggle to overcome hurdles to using online technology for PD and are hesitant to engage with others without seeing their faces. In contrast, the convenience and flexibility of

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online education allow in-service teachers to have choices, to access online modules and materials whenever and wherever they need, and to self-reflect and self-evaluate their own learning through small group discussion (Sato & Haegele, 2019), student debate (Calderón et al., 2020), and problem-based learning (Dwiyogo, 2018). In Japan, our research team found that Japanese teachers had physical and mental health risks because of the fact that they have the longest working time across 34 countries and regions, at 53.9 hours per week (Sato, Mason, & Kataoka, 2020). Japanese teachers also have longer working days, shorter breaks, and shorter sleep times than teachers in England, Scotland, or Finland (National Institute for Educational Policy Research, 2019). Therefore, online PD is considered to be a potentially useful method to facilitate connections between teachers to help them share their experiences, knowledge, and ideas with other teachers beyond their geographic location.

Public schools in Japan have become increasingly linguistically, ethnically, culturally, and religiously diverse (Furuta et al., 2022). More specifically, in rural regions, the number of Japanese-national students is declining in schools, and education services are shrinking (Mantanle, 2014), because of the aging population and low birth rate. This has led to serious economic concerns including a smaller workforce and fewer taxpayers. School districts will need new immigrant residents who can contribute to the sustainable future of education in Japan. However, in order to adequately serve this new population, Japanese teachers will need to receive training and demonstrate pedagogical knowledge and skills in relation to social justice and diversity, and facilitate inclusive and effective learning opportunities for all students. Our research team has been studying Japanese teachers' learning through online PD in teaching immigrant children in physical education, funded by the Japan Society for the Promotion of Science.

Recently, one of our research team members investigated Japanese elementary school teachers' learning experiences in a PD program for teaching physical education for Japanese language learner (JLL) children in public elementary schools. She created an online PD course which included ten modules of sixty minutes each, combined with live online sessions and on-demand video lectures (see Appendix A). Modules 1 and 10 were conducted in a live online format and modules 2 through 9 were conducted in a video-on-demand format. The modules included topics such as cultural awareness, diversity and inclusion, cultural relevance, cross-curriculum teaching of health and physical education, parental involvement, and practical cases for problem-solving. Participants were assigned to complete the ten modules and submitted reflective journal logs after each session. Additionally, they were required to submit two lesson plans, in modules 5 and 9. Data sources included a demographic questionnaire, the reflective journal logs, and the lesson plans. This study found that although teachers were anxious about teaching JLL children, they felt that they learned about cultural and religious awareness in physical education from the PD and planned ways to apply culturally responsive teaching in their physical education classes.

Additionally, Tomura et al. (2024b) created a problem-solving based online PD program using the findings of a previous study that identified problems and challenges voiced by Japanese elementary teachers regarding parental involvement of immigrant parents in relation to physical education (Tomura et al., 2024a). Tomura et al. (2024b) used visual aids to assist teachers' understanding in the PD program. Tomura et al. (2024b) designed online PD content focusing on three learning goals and objectives for elementary teachers including a) reflection on prior experiences regarding parental involvement of immigrant parents, b) theory-based learning of parental involvement of immigrant parents regarding physical education, and c) collaborative learning with other participants. The duration of the whole online PD was two months (eight weeks). One characteristic of this online PD is that the elementary teachers could access original YouTube video clips about various aspects of working with immigrant parents, which they selected according to their individual needs (Riley, 2017). Another component was a digital portfolio that was a computer-based, purposeful collection of, and reflections on, teachers' professional experiences (Espinoza & Medina, 2021).

2. Theoretical Framework

Our research team used various theoretical frameworks including andragogy theory (Knowles, 1989) in online PD in physical education for in-service teachers (e.g., Sato, Haegele, & Foot, 2017; Sato & Haegele, 2017). In andragogy theory, Knowles (1989) suggests that adult learners (in this case, teachers) should have motivation to enhance their professional skills or to satisfy their curiosity about a subject (e.g., physical education). The online PD contents were designed to incorporate teachers' prior experiences, interests, and needs. Knowles' insights are especially important for teachers' PD, where online education is often used for in-service teachers in continuing education programs, competency-based learning, and career development. Another theoretical framework, the theory of transactional distance (Moore & Kearsley, 2005), can encompass both organizational and transactional issues without losing sight of learner, institution, and nation together (Gokool-Ramdoo, 2008). In this theoretical framework, teachers and learners are both participating in the shared experience of exploring a common world (Keegan, 1993). Teachers and learners maximize their learning through mutual sharing and negotiations of meaning in such a manner that the locus of control shifts from one to others constantly through a feedback process, which Saba (2007) referred to as the "feedback loop" (Gokool-Ramdoo, 2008).

Recently, our research team has focused on transformative learning theory, which we have adopted in our online PD in physical education because we believe that online PD allows teachers to demonstrate their critical and reflective learning for professional living (Mezirow, 2000). Mezirow (2000) explains that teachers bring their assumptions, beliefs, and expectations about the world as part of a frame of reference through which they filter information and make meaning (Howie & Bagnall, 2013). More specifically, transformative learning establishes the presence of a set of interdependent core elements (i.e., practices) (Taylor, 2009) including (a) an emphasis on an individual's experiences, including prior experiences; (b) the promotion of critical self-reflection, including challenging previously held assumptions and beliefs; (c) engaging in dialogue with self and others; (d) a holistic orientation, inclusive of other ways of knowing; (e) an awareness of context, where learners develop an appreciation of how personal and sociocultural factors influence learning (see also Ellison & Sato, 2023); and (f) the importance of establishing authentic relationships among students and teachers where open communication occurs to achieve greater mutual and consensual understanding (Taylor & Laros, 2014).

3. Appropriate Method Selection

Our research problems are best approached using a qualitative research method because we need to assess online PD as a complex, multi-componential construct; address questions regarding what works for whom, when, how and why; and focus on content and instructional improvement (Busetto, Wick, & Gumbinger, 2020).

Although longitudinal qualitative research would be an appropriate way to investigate online PD in physical education (Vogl, Zartler, Schmidt, & Rieder, 2018), one of the main obstacles and challenges of longitudinal studies is retaining an adequate number of participants, since participants may drop out from the study due to various reasons and circumstances. Since it is challenging to conduct longitudinal studies that track teachers' experiences prior to, during, and following the online PD, our research team has tried to triangulate data sources and analyse various types of data. Triangulation involves the use of multiple perspectives; in our case, that includes data from semi-structured interviews with individual teachers, focus group interviews, and electronic portfolios, all of which were interpreted through the lens of our theoretical framework. Glesne (1999) posits that the use of multiple data collection methods contributes to data trustworthiness. Use of triangulation is intended to evaluate and improve the accuracy of the data (Merriam, 1998). For example, semi-structured interviews are characterized by open-ended questions and the use of an interview guide (Hijmans & Kuyper, 2007). Specifically, in our research, semi-structured interviews have helped us gain insights into teachers' subjective experiences, opinions, and motivation (Dul & Hak, 2008). Additionally, focus group interviews are used to explore teachers' expertise and experiences based on the reasons or rationale for how and why teachers behave in certain ways. Another important data source in our research on online PD is the teachers' demonstration of their learning through an electronic portfolio, which is a purposeful collection of teachers' efforts, progress, and achievement. The electronic portfolios include items such as photographs, video clips, lesson plans, and assessments based on alignment with goals and objectives (Sato & Hodge, 2017).

Additional ways to minimize researchers' biases are to use member checking and peer debriefing. For member checking, the researcher takes the data and tentative interpretations back to the participants from whom they were derived and asks them if the results are plausible (Merriam, 1998). All data must be transcribed and sent back to each participant for confirmation. Peer debriefing is a process of exposing oneself to a distinguished peer in a way paralleling an analytic session, with the purpose of exploring aspects of inquiry that might remain only implicit in the inquirer's mind (Patton, 2002). Peer debriefers evaluate the interpretations of the data as accurate and representative of the teachers' statements.

4. Results (Part I): Japanese Teachers' Learning Experiences in Online Professional Development

Based on our findings about (a) Japanese elementary school teachers' positioning in teaching physical education to JLLs (Furuta et al., 2022) and (b) Japanese elementary classroom teachers' experiences with parental involvement of immigrants regarding physical education (Tomura et al., 2024a), we embarked on a subsequent project, funded by the Japan Society for the Promotion of Science, focused on developing online PD modules using a problem-solving approach.

Our research team found that Japanese teachers learned about teaching JLLs in physical education better when critical features of effective PD were incorporated, including a content focus, active learning, coherence, duration, and collective participation (Desimone, 2009). Japanese teachers also felt that it was beneficial when the concept of culturally relevant teaching (Ladson-Billings, 1994) was embedded in the online PD.

For example, Japanese teachers felt that information about religious and spiritual practices in the PD enabled the teacher to better understand their students' religious backgrounds and apply that knowledge in a real context. Ladson-Billings (1994) defined culturally relevant pedagogy as pedagogy that empowers teachers intellectually, socially, emotionally, and politically by using cultural referents to important knowledge, skills, and attitudes. Through online PD, these Japanese teachers gained knowledge and skills and developed cultural competence. Additionally, following andragogy theory (Knowles, 1980), the Japanese teachers' prior experiences and pedagogical knowledge and skills helped them make a connection between their prior knowledge and new information about teaching JLL children in physical education while taking the online PD modules.

5. Results (Part II): Japanese Teachers' Learning Experiences regarding Parental Involvement in Online Professional Development

Tomura et al. (2024b) found that Japanese elementary teachers had positive learning experiences using the online learning materials (e.g., digital portfolios and YouTube video clips) and that these helped them find strategies to solve problems, overcome challenges, and reduce concerns regarding parental involvement. There are three themes of findings that emerged from this study: (a) *digital portfolios as a tool for problem-based learning,* (b) *transformative learning experience regarding communication with immigrant parents,* and (c) *the need for Kenshu (teacher training) for all elementary school teachers.*

One of unique findings was that online PD should include transformative learning. In transformative learning, teachers demonstrate critical reflection on their prior experiences and identify either functional or dysfunctional instances based on new learning. In the study, the YouTube video clips allowed the teachers to gain insight into how to integrate information and communication technologies (ICT) and minimize the gap in cultural context between emic (insider) and etic (outsider) views between the teachers and immigrant parents in relation to physical education (Tomura et al., 2024b). Technology-integrated PD that follows andragogy theory produces a paradigm shift that affects teachers' subsequent behaviour (using ICT) for promoting social inclusion of immigrant parents (Tomura et al., 2024b).

Overall, the online PD program helped teachers become self-directed learners, analyse their learning needs, select learning materials, and evaluate their PD experience. This study also emphasized that real-life learning experiences during this online PD program are immediately applicable to the teacher's professional responsibilities in terms of parental involvement of immigrant parents in relation to physical education (see Appendix B).

6. Recommendations and Conclusions

This review article introduced how our research team served as a change agent and supported Japanese elementary school teachers not only as processors of cognitive information, but also through transformational learning by sensing, visualizing, perceiving, and learning with others in the online PD (Cercone, 2008). However, there are still some improvements that need to be done in the future. In this section, our research team introduces several recommendations for online PD in relation to physical education.

First, our research team recommends that school districts offer online PD workshop(s) and a mentoring system that provide a benchmark for administrators of school districts to evaluate the quality of educational services (for teaching JLL children in physical education) (Sato, Tsuda, McKay, Furuta, & Kajita, 2020). There are two things our research team needs to improve for enhancing the quality of online PD which allows school districts, administrators, and teachers gain knowledge of analytical and interpretative records of reflection on their practices, values, and strategies, and help enhance their critical thinking skills to identify their professional growth.

Second, in Japan, lesson study (*jugyo kenkyu* in Japanese) is an important organized PD opportunity for elementary teachers (Saito, 2012) and makes various types of knowledge more visible through colleagues' and mentors' feedback and suggestions about pedagogy and students' reflective and critical thinking (Sato, Tsuda, Ellison, & Hodge, 2020). Our research team encourages school districts to develop online lesson study for elementary teachers. In this way, school districts can automatically secure online data including lessons, bulletin board communication, feedback communication, and lesson reflections, so that school districts may continuously analyse and share this information with new teachers.

Third, our research team suggests that pair or collaborative reading and theory learning while developing online PD may enhance learning in physical education (Sato & McKay, 2020). This strategy provides our research team more opportunity to learn about establishing another or alternative theoretical framework that increases the quality of online PD contents (Li & Nes, 2001). Through the experiences, our research team can share their prior knowledge and experiences and build new knowledge through theory learning in online PD.

To better support future researchers, this study encourages physical education researchers and graduate students to learn how to develop a blueprint of the theoretical framework, research method, and presentation of the results using online PD research sources in colleges and universities. Our research team hopes that Japanese teachers and researchers will build capacity, expertise, and knowledge to improve the teaching of JLLs as well as involvement of their parents through a spectrum of online PD in physical education.

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Institutional Review Board Statement
The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the University of Tsukuba (protocol code 体 022-100, approved September 26th, 2022).

Informed Consent Statement
Informed consent was obtained from all subjects involved in the study.

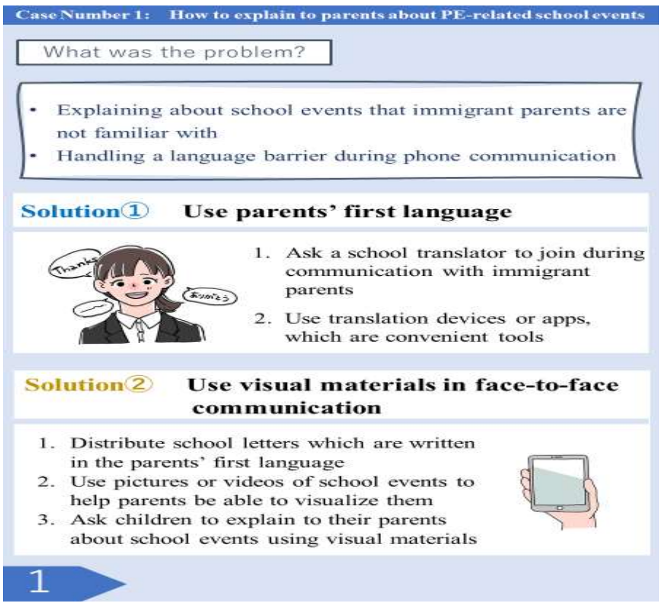
Conflicts of Interest
The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Module Description

1. Introduction	Guidance of the online course, Sharing the experience in teaching JLL children
2. Cultural awareness and cultural understanding	Understanding 8 cultural competencies, and the process of cultural understanding
3. Diversity and Inclusion in PE	The relevance between racial, religious, and refugee backgrounds and PE/Sport
4. Culturally relevant pedagogy and culturally responsive pedagogy	Understanding the concept of culturally relevant/responsive pedagogy, and the teachers' competencies in teaching diverse children
5. Reflection	Looking back on their lesson practices
6. Health education with comparison in other countries and Japan	Case studies comparing the school culture in other countries and Japan, and critical thinking about teaching health education to JLL children.
7. Parental involvement	Case studies to promote parental involvement
8. Case studies of PE including JLL children	Case studies of integrating the concept of cultural relevancy in PE
9. Application of Action plan	Application their learning to their PE lesson plan.
10. Group discussion	Online discussion about their learning and teaching JLL children

Appendix B



References

Avalos, B. (2011). Teacher professional development in teaching and teacher education over ten years. *Teaching and Teacher Education, 27*(1), 10-20. doi.org/10.1016/j.tate.2010.08.007

Busetto, L., Wick, W., & Gumbinger, C. (2020). How to use and assess qualitative research methods. *Neurological Research and Practice, 2*(14), 1-10. doi.org/10.1186/s42466-020-00059-z

Calderón, A., Meroño, L., & MacPhail, A. (2020). A student-centred digital technology approach: The relationship between intrinsic motivation, learning climate and academic achievement of physical education pre-service teachers. *European Physical Education Review, 26*(1), 241-262. doi.org/10.1177/1356336X19850852

Cercone, K. (2008). Characteristics of adult learners with implications for online learning design, AACE Journal, 16(2), 137-159. https://dl.icdst.org/pdfs/files1/02f439c51a7d7528bfa987651d20269e.pdf

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199. doi.org/10.3102/0013189X08331140

Dul, J., & Hak, T. (2008). *Case study methodology in business research.* Abingdon, England: Routledge.

Dwiyogo, W. D. (2018). Developing a blended learning-based method for problem-solving in capability learning. *Turkish Online Journal of Educational Technology-TOJET 17*(1), 51-61.

Ellison, D., & Sato, T. (2023). Curriculum negotiation in an undergraduate fitness education course for transformative learning. *Journal of International Kinesiology in Higher Education, 7*(1), 61-75. doi.org/10.1080/24711616.2021.1946451

Espinoza, A. Q., & Medina, S. K. (2021). Understanding in-service teachers' learning experience while developing an electronic portfolio. *Teaching English with Technology, 21*(3), 19-34.

Furuta, Y., Sato, T., Miller, R. T., Kataoka, C., & Tomura, T. (2022). Public elementary school teachers' positioning in teaching physical education to Japanese language learners. *European Physical Education Review, 28*(4), 1006-1024. doi.org/10.1177/1356336X221104912

Glesne, C. (1999). *Becoming qualitative researchers: An introduction.* New York, NY: Longman.

Gokool-Ramdoo, S. (2008). Beyond the theoretical impasse: Extending the applications of transactional distance theory. *International Review of Research in Open and Distance Learning, 9*(3), 1–17. doi.org/10.19173/irrodl.v9i3.541

Hijmans, E., & Kuyper, M. (2007). Het halfopen interview als onderzoeksmethode [The half-open interview as research method]. In L. PLBJ & H. TCo (Eds.), *Kwalitatief onderzoek: Praktische methoden voor de medische praktijk* (pp. 43–51). Houten: Bohn Stafleu van Loghum.

Howie, P., & Bagnall, R. (2013). A beautiful metaphor: Transformative learning theory. *International Journal of Lifelong Education, 32*(6), 816–836. doi.org/10.1080/02601370.2013.817486

Keegan, D. (1993). *Theoretical principles of distance education.* London: Routledge.

Knowles, M. S. (1989). *The making of an adult educator.* San Francisco, CA: Jossey Bass.

Knowles, M. S. (1980). *The modern practice of adult education: From pedagogy to andragogy.* Englewood Cliffs.

Ladson-Billings, G. (1994). *The dream keepers: Successful teaching for African Ameri can students.* San Francisco, CA: Jossey-Bass

Li, D., & Nes, S. (2001). Using paired reading to help students become fluent and accurate readers. *Reading Improvement, 38*(2), 50-61.

Luguetti, C., Enright, E., Hynes, J. & Bishara, J. A. (2021). The (im) possibilities of praxis in online health and physical education teacher education. *European Physical Education Review, 28*(1), 57-77. doi.org/10.1177/1356336X211016485

MacPhail, A., & Lawson, H. (2020). *School physical education and teacher education: Collaborative redesign for the 21st century*: London: Routledge.

Matanle, P. (2014). Ageing and Depopulation in Japan Understanding the Consequences for East and Southeast Asia in the 21stCentury. In H. Dobson (Ed.), East Asia in 2013: A Region in Transition. White Rose East Asia Centre and Foreign and Commonwealth Office Briefing Papers (pp. 30–35). Sheffield: WREAC.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass Publisher.

Mezirow, J. (2000). Learning to think like an adult. In J. Mezirow (Ed.), *Learning as transformation: Critical perspectives on a theory in progress* (pp.3-33). San Francisco, CA: Jossey-Bass.

Moore, M., & Kearsley, G. (2005). *Distance education: A systems view* (2nd ed.). Belmont, CA: Thomson Wadsworth.

Murtagh, E., Calderon, A., Scanlon, D., & MacPhail, A. (2023). Online teaching and learning in physical education teacher education: A mixed studies review of literature. *European Physical Education Review,* 1-20. doi.org/10.1177/1356336X231155793

National Institute for Educational Policy Research. (2019). The improvements to the courses of study for elementary, lower secondary and upper secondary schools. Retrieved from https://www.nier.go.jp/04_kenkyu_annai/pdf/improvement_of_the_courses_of_study.pdf.

Patton, M. (2002). *Qualitative research and evaluation methods.* (3rd ed). Thousand Oaks, CA: Sage.

Perry, E. (2023). Teacher professional development in changing circumstances: The impact of COVID-19 on schools’ approaches to professional development. *Educational Sciences*, *13*(1), 48. doi.org/10.3390/educsci13010048

Peters, O. (2003). Learning with new media in distance education. In M. G. Moore & W. G. Anderson (Eds.), *Handbook of distance education* (pp. 87–112). Mahwah, NJ: Elbaum.

Riley, J. (2017). Integrating YouTube videos in online teacher education courses. *Journal of Teaching and Learning with Technology, 6*(1), 81-84. doi.org/10.14434/jotlt.v6.n1.19526

Saba, F. (2007). A system approach in theory building. In M. G. Moore (Ed.) *Handbook of distance education.* (pp. 43–57). Mahwah, NJ: Lawrence Erlbaum

Saito, E. (2012). Key issues of lesson study in Japan and the United States: a literature review. *Professional Development in Education, 38*(5), 777–789.

Sato, T., Haegele, J. A., & Foot, R. (2017). In-service physical educators’ experiences of an online adapted physical education endorsement program. *Adapted Physical Activity Quarterly, 34*(2), 162-178. doi.org/10.1123/apaq.2016-0002

Sato, T., & Haegele, J. A. (2019). Physical education pre-service teachers’ academic and social engagement in online kinesiology course. *Journal of Digital Learning in Teacher Education, 35(3), 181-196. doi: 10.1080/21532974.2019.1619108*

Sato, T., & Haegele, J. A. (2018). Physical educators’ engagement of online Adapted physical education graduate courses. *Professional Development in Education, 44*(2), 272-286. doi.org/10.1080/19415257.2017.1288651

Sato, T., & Haegele, J. A. (2017). Professional development in adapted physical education with graduate web-based professional learning. *Physical Education & Sport Pedagogy, 22*(6), 618-632. doi.org/10.1080/17408989.2017.1310832

Sato, T., & Hodge, S. R. (2017). African American teacher candidates' experiences in teaching secondary physical education. *Journal of Teaching in Physical Education, 36*(1), 97-112. doi.org/10.1123/jtpe.2016-0010

Sato, T., Kataoka, C., Burge-Hall, V., Furuta, Y., Izumi, A., & Tomura, T. (2022). Undergraduate students’ learning experience as part of an online sexuality education workshop in Japan. *Health Education Journal, 81*(4), 387–398. doi.org/10.1177/00178969221082385

Sato, T., Mason, S., & Kataoka, C. (2020). Japanese elementary teachers’ professional experiences through long working hours. *Issue of Educational Research, 30*(4), 1522-1538. https://www.iier.org.au/iier30/sato.pdf

Sato, T., & McKay, C. (2020). Japanese physical education graduate students’ learning about research skill development. *Curriculum Studies in Health and Physical Education, 11*(1), 34-49. doi.org/10.1080/25742981.2019.1685898

Sato, T., Tsuda, E., Ellison, D. W., & Hodge, S. R. (2020). Japanese elementary teachers’ professional development experiences in physical education lesson studies. *Physical Education & Sport Pedagogy, 25*(2), 137-153.

Sato, T., Tsuda, E., McKay, C., Furuta, Y., & Kajita, K. (2020). Japanese elementary teachers’ professional development experiences of teaching physical education. *The Teacher Educator, 55*(4), 373-391. doi.org/10.1080/08878730.2020.1801925

Taylor, E. (2009). Fostering transformative learning. In J. Mezirow & E. Taylor (Eds.), *Transformative learning in practice: Insights from community, workplace, and higher education* (pp. 3–17). San Francisco, CA: Jossey-Bass.

Taylor, E. W., & Laros, A. (2014). Researching the practice of fostering transformative learning: Lessons learned from the study of andragogy. *Journal of Transformative Education, 12*(2), 134–147. doi.org/10.1177/1541344614548589

Tomura, T., Sato, T., Miller, R. T., & Furuta, Y. (2024a). Japanese elementary classroom teacher’s experiences with parental involvement of immigrants regarding physical education. *Education 3-13, 52*(2), 185-200. doi.org/10.1080/03004279.2022.2081351

Tomura, T., Sato, T., Miller, R. T., & Furuta, Y. (2024b). Japanese elementary teacher’s experiences during online professional development regarding involvement of immigrant parents in physical education. *European Physical Education Review, 30*(2), 228-249. doi.org/10.1177/1356336X231199677

Tsuda, E., Sato, T., Wyant, J., & Hasegawa, E. (2019). Japanese elementary physical education teachers’ professional development at depopulated rural school districts. *Curriculum Studies in Health and Physical Education, 10*(3), 262-276. doi.org/10.1080/25742981.2019.1635508

Vogl, S., Zartler, U., Schmidt, E-M., & Rieder, I. (2018). Developing an analytical framework for multiple perspective, qualitative longitudinal interviews (MPQLI). *International Journal of Social Research Methodology, 21*(2), 177-190. doi.org/10.1080/13645579.2017.1345149

Digital Life

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Special Issue: Digital Technology in Sports and Physical Activity
Article

A case study of the use of match video analysis tools in Judo: Attempts of visualizing the competition realities of an athlete

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Abstract
In this study, we analyzed match videos of a university Judo Player (Player A) utilizing the SPLYZA TEAMS matched video analysis tool. This is the first case study of Judo match analysis using the SPLYZA TEAMS software. A total of 13 matches involving Player A were analyzed in this study. Prior to the analysis, Player A formulated three hypotheses for the matching implementation. The analysis rejected two of the three hypotheses established at the beginning of the study. However, a notable trend emerged, revealing a proclivity for the Kumite situation for initiating Nage-waza from disadvantaged positions in matches that resulted in a loss. This novel finding was obtained by analyzing the data using the SPLYZA TEAMS software.

Keywords: Judo; match analysis; analysis tool; visual analysis

1. Introduction

Judo is a Japanese martial art that was established in 1882 by Jigoro Kano. Judo practitioners wear Judo-gi, and engage in dynamic contests using Nage-waza and Katame-waza to assert dominance over their opponents. Since its recognition as an official sport at the 1964 Tokyo Olympics (Murata, 2011), judo has garnered international recognition, reaching over 200 countries and regions (International judo federation, 2023), making it a familiar facet of Japanese culture worldwide.

Despite the sport's widespread practice, no studies or reports have analyzed competition videos using tools or applications related to competition analysis. While previous research has employed statistical methods to analyze Judo competitions and competitiveness (Ishii, et al., 2021; Maekawa et al., 2014) and analyzed score-earning tendencies based on competition videos, there remains a gap in comprehensive competition analysis, especially using approved tools (Miyake, et al., 2021; Ito et al., 2019). Moreover, the Scientific Research Department of the All Japan Judo Federation have developed its own competition video analysis tool, GOJIRA (Mynavi Books, 2017); however, this approach has yet to be approved for general use.

Although there are limited cases of competition analyses using competition videos for Judo, competition analysis is vital for enhancing competitiveness, analyzing opponents, and developing strategies.

Therefore, to address this, the present study attempts to analyze competitive Judo footage. As GOJIRA has not yet been approved for general use, we used SPLYZA TEAMS (https://products.splyza.com/teams/), a competition video analysis tool provided by SPLYZA Corporation. We analyzed competition video of Player A, a university student athlete for whom the author was involved in coaching. Player A sought to further improve his athletic performance at

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the time of this study in April 2022. Therefore, the author proposed the abovementioned visualization of the actual competition phase in SPLYZA TEAMS, and Player A agreed.

The characteristics of Player A are as follows: He was a 21-year-old male university student and judo competitor, with a Judo Dan of Second and 15 years of competition experience. Competing in the 81 kg weight class, he had placed 5th in the previous year's national university championships at the time the analysis began (April 2022). He is a Right-Kumite in Judo's competitive activities, and his favorite technique is Seoinage.

In this study, SPLYZA TEAMS was used to analyze Player A's competition videos. This study focused a total of 13 of Player A's games in 2021 and 2022. The competition results for 2021 and 2022 are as follows:

1) 2021 National Athletic College Tournament: lost in the 1st round (one match)
2) 2021 National University Championship: 5th place (four matches)
3) 2022 Japan National Championship: lost in the 2nd round (two matches)
4) 2022 Regional University Championship: champion (five matches)
5) 2022 Japan National Championship: lost in the 1st round (one match)

*National Championships were held twice in 2022, because the 2021 championship was postponed due to Covid-19. Thus, the competition for 2021 was held in 2022.

We used a competitive video analysis tool, SPLYZA TEAMS, which can be used on websites or through Smartphone and Tablet applications. SPLYZA TEAMS has be used for analyses of various sports, including basketball (Kiba, et al., 2022; Kitazawa, et al., 2019) and tennis (Kitamura, 2021). However, the analysis of Judo using this method has not been explored. Therefore, this is the first study to report a competitive analysis of Judo using SPLYZA TEAMS. This study aimed to analyze Judo competition videos using analytical tools to visualize the reality of Judo competitions and seek cues for enhancing athletic performance.

To achieve this, we developed three hypotheses. While conducting this study, Player A believed that there was a difference in his attack style between matches that he won and lost. Based on this opinion, the author consulted with Player A and formulated the following hypotheses:

1) Player A heavily utilizes Seoinage and the Kouchi-gari associated with the preparatory movements of Seoinage.
2) Match outcomes correlate with the frequency of Player A's Nage-waza.
3) In winning matches, Player A used Seoinage extensively, while lost matches involved fewer Seoinages.

2. Methods

2.1. Analysis using SPLYZA TEAMS

SPLYZA TEAMS facilitates the loading of competition videos and uses a function called "tags" to incorporate evaluation factors to the competition analysis (Fig. 1). While no predefined evaluation factors existed for Judo, the author (a 5th dan in judo and coach of a university judo team) and Player A collaboratively identified and developed the following evaluation factors (tags) specifically tailored for judo. In Judo, there are two skill systems, Nage-waza and Katame-waza, but because Player A primarily utilized Nage-waza as his main attacking technique, this analysis focused on Nage-waza.

2.1.1. General overview of the match

A) Details of match settlements when victorious (Ippon, Yusei-gachi, Hansoku-gachi).
B) Details of match settlements when defeated (Ippon, Yusei-make, Hansoku-make).
C) Kumite stance combinations (Aiyotsu & Kenkayotsu).
*Aiyotsu: both competitors standing in a closed stance; Kenkayotsu: both competitors standing in an open stance (Ito, et al., 2015).

2.1.2. Match details

A) Player responsible for initiating Nage-waza (Player A, Opponent player).
B) Time periods attempting own Nage-waza in the match (0~1 min, 1~2 min, 2~3 min, etc.).
C) Kumite situation when Nage-waza was performed (standard, advantaged situation, disadvantaged situation, one-sided grip, both collars or sleeves).
D) Name of Nage-waza performed (Seonage, Uchi-mata, O-uchi-gari).
E) Scores of Nage-waza (Ippon, Waza-ari, No.).
F) Details of penalties (Shido) (non-combativity, not taking a grip, defensive position, Illegal Kumi-kata, etc.)
G) Object of penalties (Shido) (Player A, Opponent, both players).

2.2. Conducting Analysis

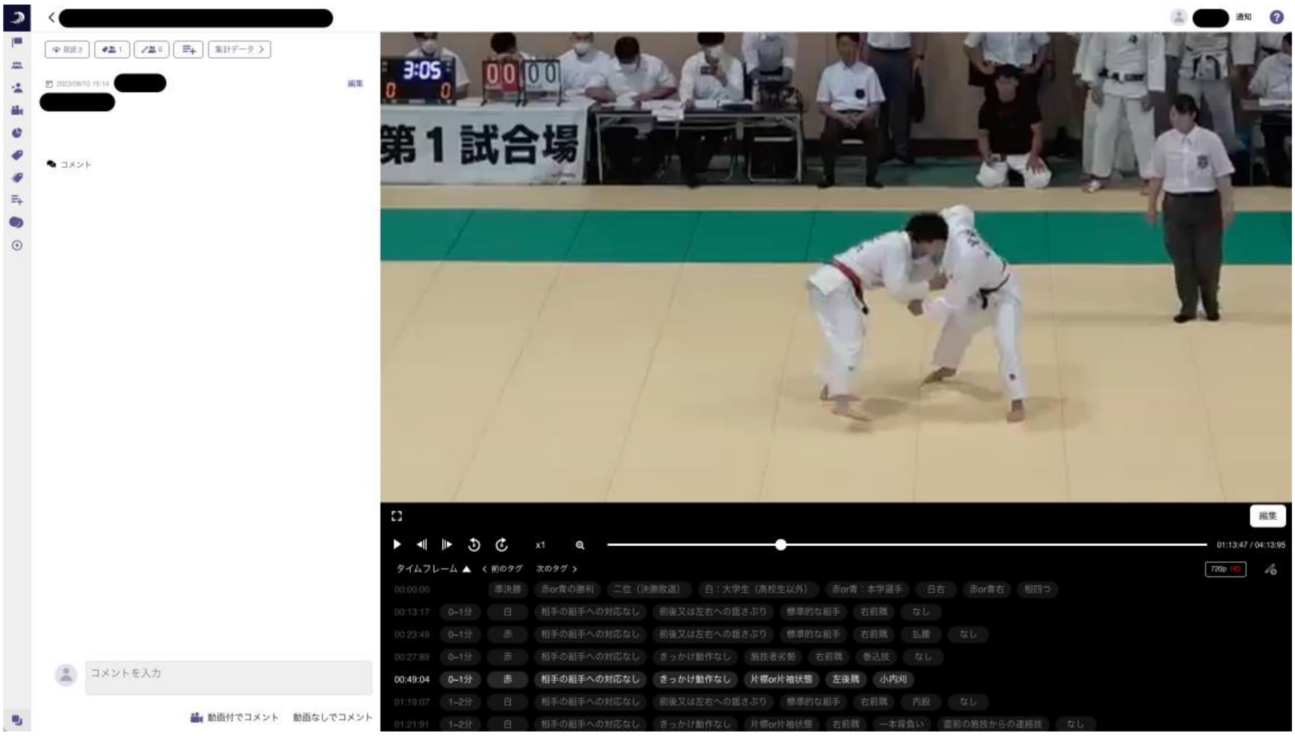

Fig.1: Screen shot of analysis using SPLYZA TEAMS for Judo match

Player A, in collaboration with the author, conducted the analysis after the last match (the 2022 Japan National Championship). To validate the study's hypotheses, the videos of all matches were tagged, and the tags were systematically tabulated for each match won and lost. Additionally, we examined Player A attack strategy in each match. The tag summary data were obtained from SPLYZA TEAMS in Microsoft Excel. A graph was then created based on the tag summary data.

3. Results

3.1. Overview of the matches

A summary of the 13 matches is presented in Fig. 2. Of the nine winning matches, Ippon won six (67%), Yusei-gachi won two (22%), and Hansoku-gachi by Shido3 won one (11%). Of the four lost matches, Ippon had one (25%), Yusei-make had two (50%), and Hansoku-make by Shido 3 had one (25%). The Kumite combinations of Player A and Opponent were five (38%) for Aiyotsu and eight (62%) for Kenkayotsu. Nage-waza occurred 130 times in the 13 games, with 78 instances by Player A (60 %) and 52 by the Opponent (40 %).

The Nage-waza comprised 12 types, including 59 (45%) Seoinage, 24 (18%) Kouchi-gari, and 10 (8%) Uchi-mata, in descending order of frequency. For the Nage-waza evaluation, there were 118 (91%) instances of no score, seven (5%) of Waza-ari, and five (4%) of Ippon. There were 18 instances of shido in the 13 games, with "Not taking a grip" accounting for 10 (56%), "Non-combativity" for five (28%), "Illegal kumi-kata" for two (11%), and "Defensive position" for one (5%). The "Illegal kumi-kata" occurred in two (11%), and "Defensive position" occurred in one (5%) match. The object of Shido was nine (50%) for both players, six (33%) for Player A three (17%) for the Opponent players.

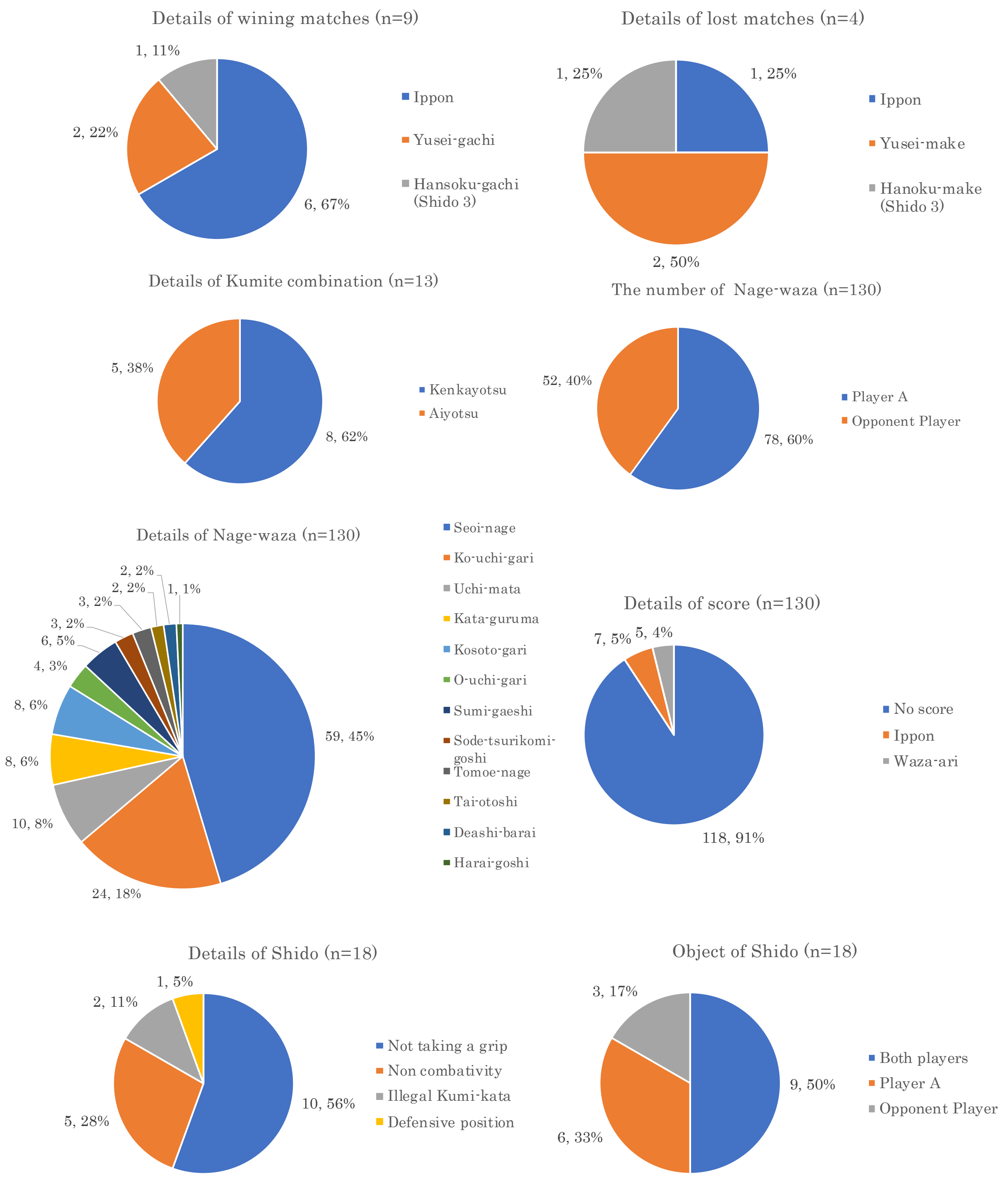

Fig.2: Overview of 13 matches

3.2. Details of the winning matches (Player A and Opponent players' summary)

The details of the nine winning matches are summarized in Fig. 3. The Kumite combinations of Player A and Opponent players were four (44%) for Aiyotsu and five (56%) for Kenkayotsu. Ninety-nine Nage-waza were performed in the nine games, with 57 (58%) by Player A and 42 (42%) by Opponents. Nage-waza comprised 10 different types, with Seoinage accounting for 49 (50%), kouchi-gari for 18 (18%), and kosoto-gari for seven (7%). Nage-wazas were evaluated with a no score of 90 (91%); Ippon at six (6%); and Waza-ari at three (3%). Shido instances totaled 11 in nine games, with four (37%) for "Non-combativity," four (36%) for "Not taking a grip," two (18%) for "Illegal kumi-kata," and one (9%) for "Defensive position." Illegal kumi-kata" accounted for two (18%) and "Defensive position" for one (9%). The Object of Shido was Player A with four (37%), both players with four (36%), and Opponent players with three (27%).

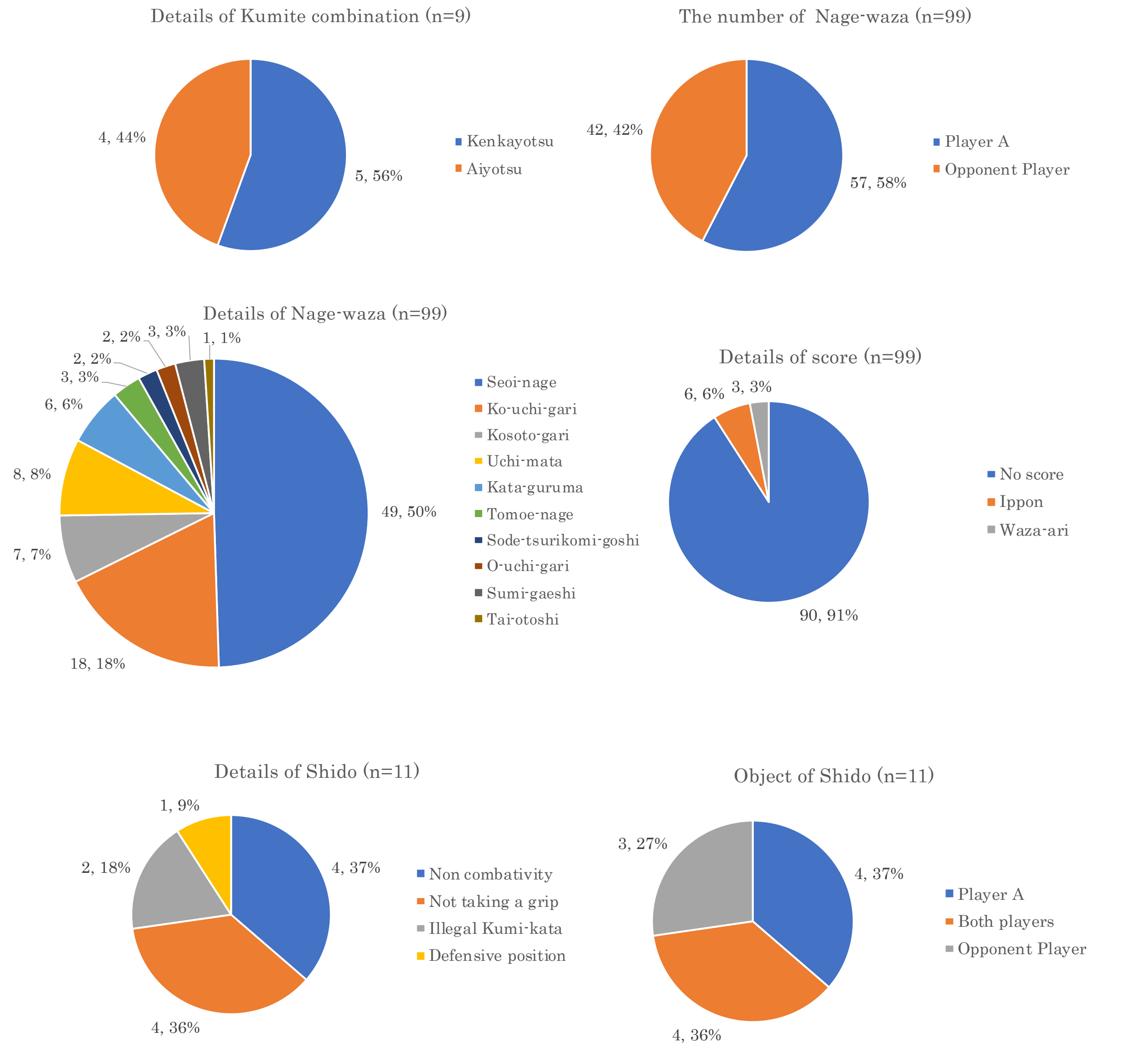

Fig.3: Details of 9 winning matches

3.3. Player A's content in the winning matches

To verify the Nage-waza setups by Player A in the winning matches, tags were tabulated, focusing on Player A's Nage-waza, and a graph was created. A detailed description of Player A’s nage-waza (n=57) in the winning match is shown in Fig. 4. The most common time period that Player A performed Nage-waza was "1~2 min", accounting for 17 (30%) of the total instances, followed by "0~1 min" and "2~3 min". The "Standard" Kumite situation when Nage-waza was performed was the most common, accounting for 28 (49%) of the total. The advantageous situation accounted for 18 (32%). Seoinage accounted for 36 (63%), followed by Kouchi-gari with nine (16%). Nage-waza evaluations resulted in no score for 49 (86%), Ippon for four (7%), and Waza-ari for four (7%).

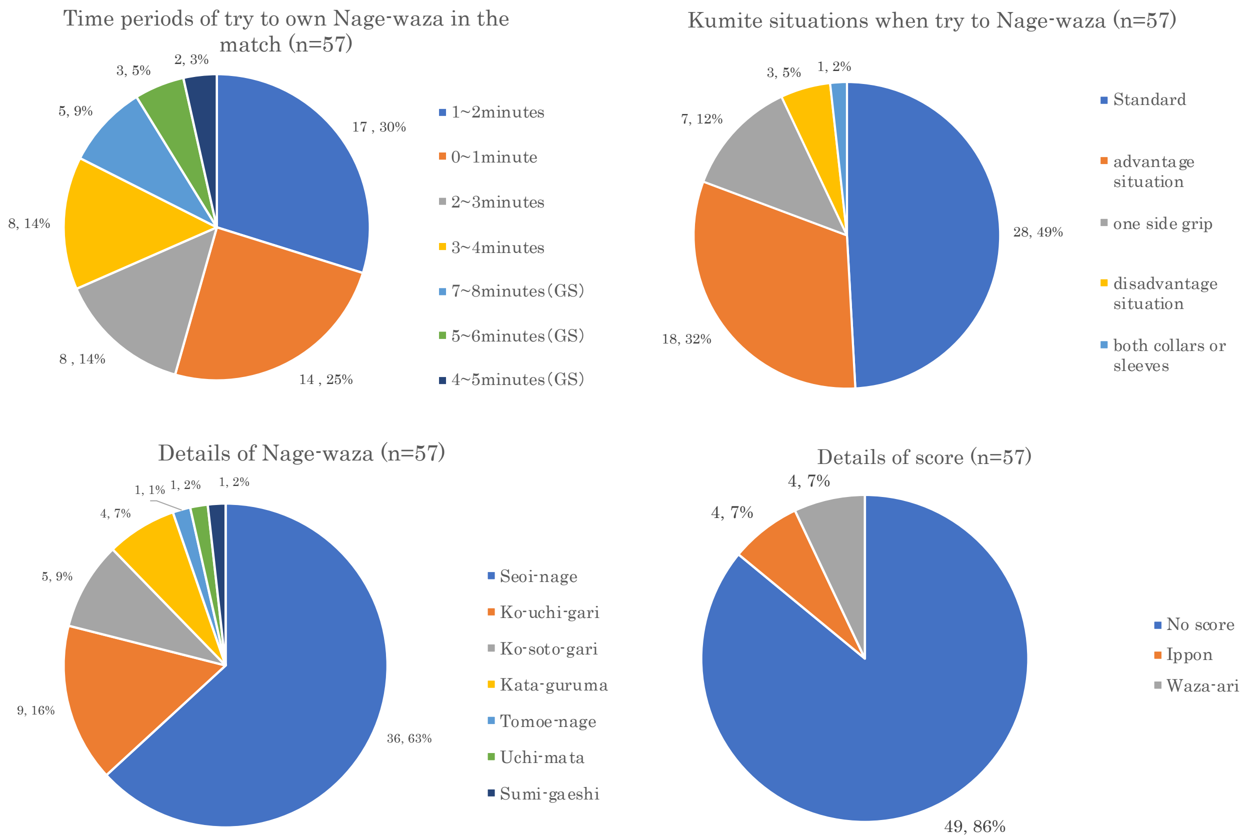

Fig.4: Details of contents of player A in 9 winning matches

3.4. Details of the lost matches (Player A and Opponent players' summary)

The four games lost matches are illustrated in Fig. 5. The Kumite combination of Player A and Opponent players was one (25%) for Aiyotsu and three (75%) for Kenkayotsu. The number of Nage-wazas conducted in the four matches was 31, with 17 (55%) by Player A and 14 (45%) by Opponent players. Nage-waza comprised 11 different types, with Seoinage accounting for 10 (32%), Kouchi-gari for five (16%), and Ouchi-gari for two (7%). Nage-waza was evaluated with no score at 28 (90%), Ippon at one (3%), and Waza-ari at two (7%). Shido instances totaled seven in four matches, with six (86%) for "Not taking a grip" and one (14%) for "Non-combativity." There were five (71 %) objects of shido for both players and two (29%) for Player A.

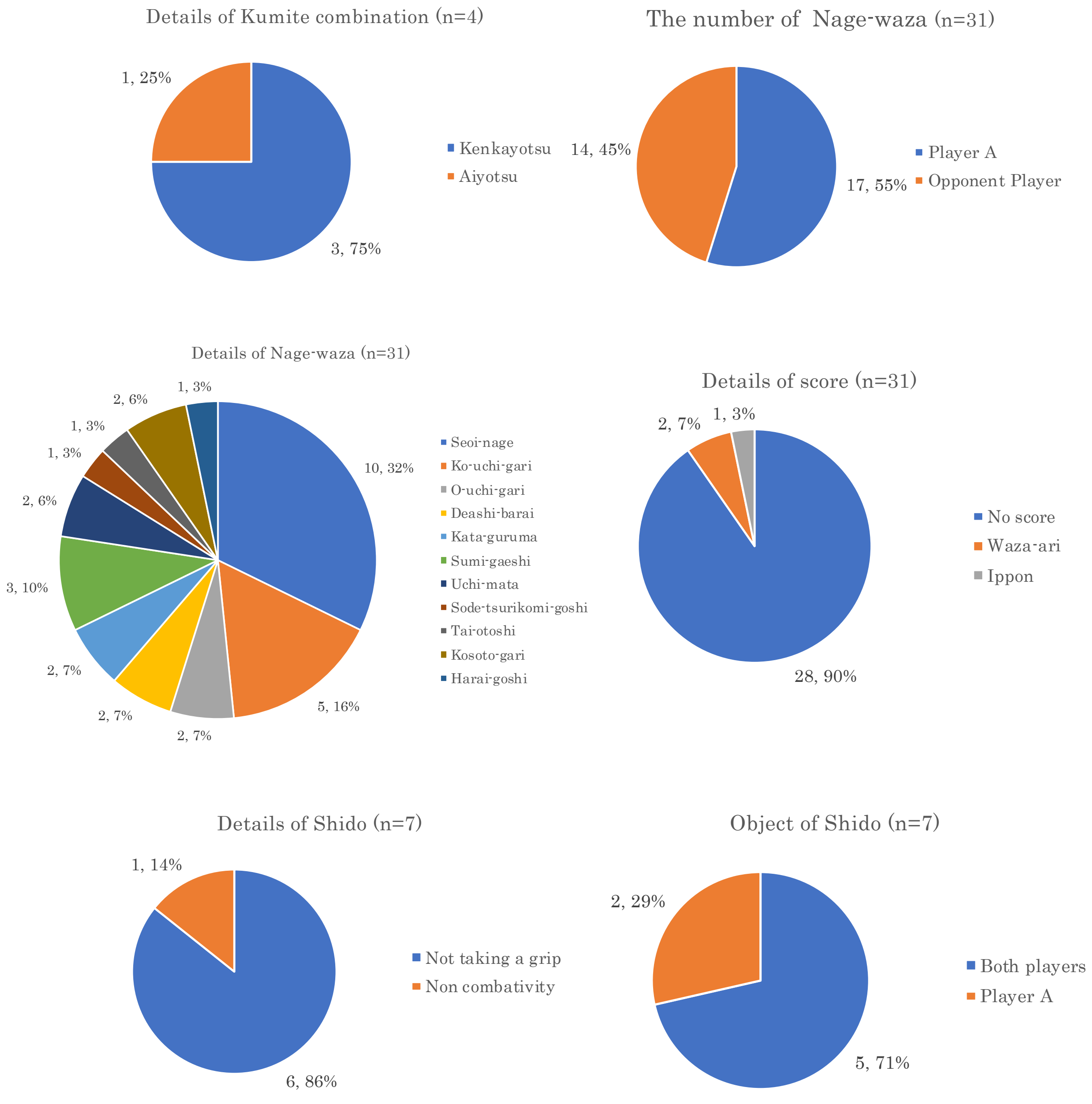

Fig.5: Details of 4 lost matches

3.5. Player A's content in the lost matches

To verify the Nage-waza Player A setups in the lost matches, tags were tabulated, focusing on Player A's Nage-waza, and a graph was created. The details of Player A's Nage-waza (n=17) in the lost matches is shown in Fig. 6. The most common time period for Player A to perform Nage-waza was "1~2 min", accounting for four (23%) of the total, followed by "0~1 min" and "2~3 min". Kumite situations when Nage-waza was performed were as follows: "Disadvantage situation" in six (35%), "Standard" in five (29%), "One side grip" in three (18%), "Both collars or sleeves" in two (12%), and "Advantage Situation" in one (6%). Nine (53%) were Seoinage and two (11%) were Kata-Guruma. None of the Nage-waza evaluations were scored.

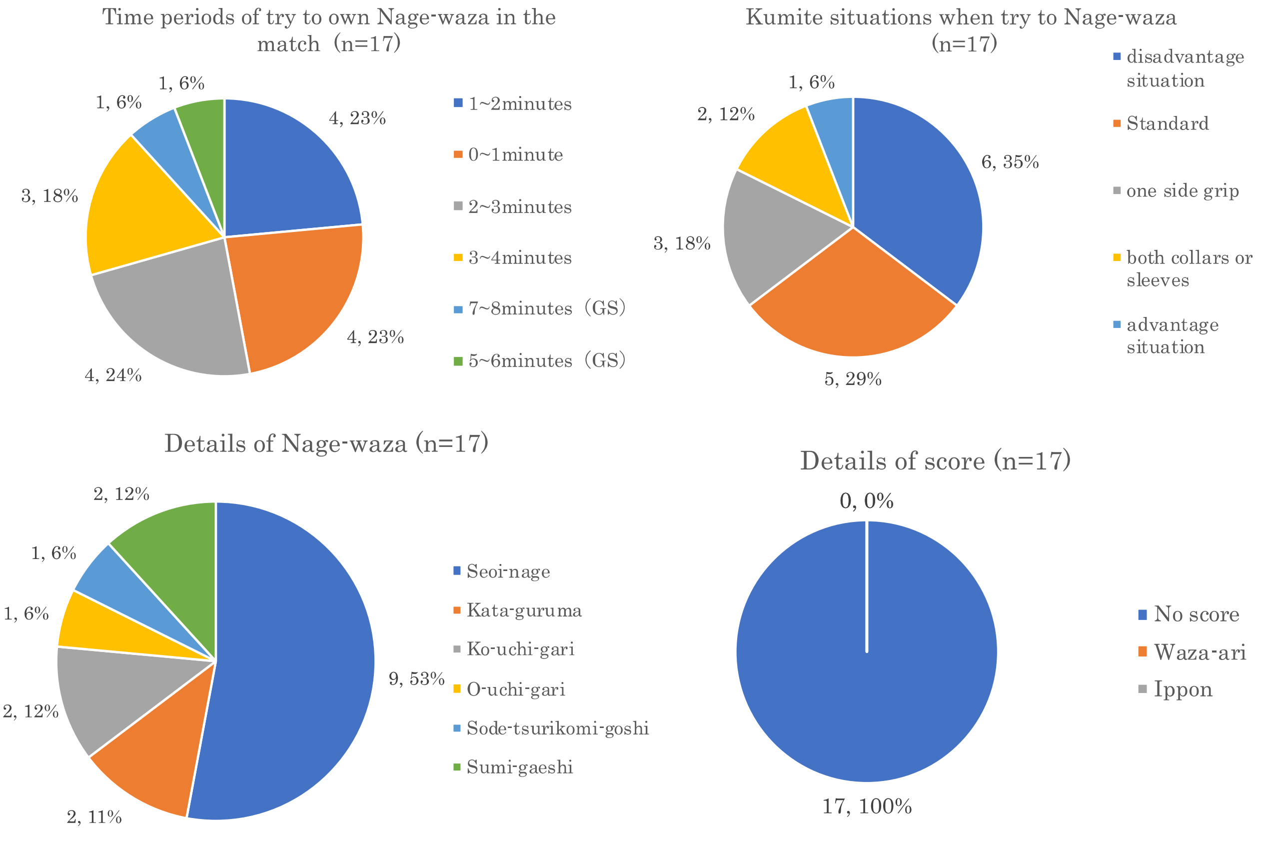

Fig.6: Details of contents of player A in 4 lost matches

4. Discussion

4.1. About overview of the matches

Focusing on the winning matches in Fig. 2, six out of nine matches were Ippons, indicating Player A’s proficiency with the most Ippons. Regarding the number of Nage-wazas, Player A had 60% and Opponent players had 40%. Regardless of the match outcome, Player consistently took the lead in initiating a larger percentage of Nage-wazas. Regarding the evaluation of Nage-waza, no scores accounted for 91%, indicating the difficulty in obtaining a score for Judo. Regarding Shido instances, "Not taking a grip" was the most common response, and both players accounted for 50% of the objects in Shido. This implies an intense struggle by both players to manipulate the Kumite situation in their favor, underscoring the competitive intensity observed in the analyzed matches.

4.2. Details of the winning matches

Focusing on Fig. 3, Aiyotsu and Kenkayotsu account for almost half of the total number of Kumite combinations. Indicating Player A’s weakness in either Aiyotsu or Kenkayotsu. Regarding the number of Nage-wazas, Player A accounted for 58% and Opponent players for 42%; therefore, Player A was not considered the more dominant player. However, regarding the type of Nage-waza, Seoinage accounted for 50% and Kouchi-gari for 8%. Therefore, Hypothesis 1 is likely to be supported, although a detailed examination of the percentage of Player A's Nage-waza is warranted.

4.3. Player A’s content in the winning matches

Examining Player A's performance in the winning matches, in Fig. 4, reveals that half of the Nage-waza instances occurred within the "1~2 min" and "0~1 min" time periods, suggesting a propensity for initiating Nage-waza early in the match. However, the number of Nage-wazas did not significantly decrease in later time periods, suggesting that Player A is an endurance player. In Kumite situations when Nage-waza was executed, "Standard" was the most popular (49%), followed by the "Advantage situation" (32%). This indicates that Player A primarily executed Nage-waza in the "Standard" or "Advantage situation" during the winning matches. Analyzing Player A's specific Nage-waza in winning matches, Seoinage and Kouchi-gari accounted for 63% and 16%, respectively, of the total of 79%. This aligns with Hypothesis 1 that “Player A uses a lot of Seoinage and the Kouchi-gari associated with the preparatory movements of Seoinage.”

4.4. About details of the lost matches

The lost matches are shown in Fig. 5. The analysis of the number of Nage-wazas in the lost matches revealed that Player A initiated 55%, while the Opponent player initiated 45%. Interestingly, this percentage distribution mirrors the results observed in the winning matches (58% for Player A and 42% for Opponent Players). Thus, Player A's percentage of initiating Nage-waza was consistent regardless of whether he won or lost. Consequently, Hypothesis 2, "Winning or losing a match is related to the number of one's own Nage-waza," was rejected.

4.5. Player A’s content of the lost matches

The analysis of Player A’s in lost matches are shown in Fig. 6. The time periods of Nage-waza were "1~2 min" and "0~1 min" in 46% of cases, consistent with that of the winning matches. Regarding the nage-waza content, seoinage was the most common (53%), followed by kouchi-gari (12%), similar to in the winning matches. This contradicts Hypothesis 3, " Winning matches use a lot of Seonage. In other words, lost matches did not use many Seonages." Furthermore, the analysis of Kumite situations when initiating Nage-waza in lost matches reveals that the “Disadvantage situation" was the most common (35%), followed by "Standard" (29%), "One side grip" (18%), "Both collars or sleeves" (12%), and "Advantage situation" (6%). The "Disadvantage situation" was uncommon in the winning matches (5%), and the "Advantage situation" was the most common (49%), indicating that the Kumite situation in the losing matches differed from that in the winning matches. In the lost matches, the number of Nage-waza in the "disadvantage situation" was high, suggesting that Player A struggled to gain an advantage in Kumite-scramble during the lost matches; this contradicts the initial hypothesis. This underscores the importance of video analysis in uncovering nuanced aspects of performance, as demonstrated by SPLYZA TEAMS in this study.

5. Conclusions

The author and Player A formulated three hypotheses to understand match reality. Utilizing SPLYZA TEAMS for video analysis led to the rejection of two hypotheses. Notably, the comparison between winning and lost matches revealed that in lost matches, the Kumite situation often started with "Disadvantage situation" followed by the initiation of Nage-waza. This discrepancy between athletes between athletes' perceptions and the analytical insights provided by SPLYZA TEAMS highlights the value of such tools in objectively evaluating match dynamics. While the initial hypotheses were disproven, a significant revelation emerged: Nage-waza in lost matches tended to originate from a disadvantaged Kumite situation. For Player A, enhancing Kumite skills became a pivotal factor in elevating competitive performance. This study not only refuted preconceived notions but also offered valuable insights for targeted improvement in Player A's approach to matches.

Author Contributions

Conceptualization, R. O.; methodology, T. O. and D. F.; software, R. O.; validation, R. O. and Y. O.; formal analysis, R. O.; writing—original draft preparation, R. O.; writing—review and editing, R. O. and Y. O.

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Conflicts of Interest

The authors declare no conflict of interest.

References

International judo federation (2023). Retrieved November 2,2023, from https://www.ijf.org/countries

Ishii, T., Suzuki, Y. (2021). Development of a method for evaluating athletic performance in competitive matches using rating, https://takanoriishii.jp/rating_wjc2021/#title1 (Last access date: 2023/11/02).

Ito, K., Hirose, N., Maekawa, N. (2019). Characteristics of Re-gripping Techniques Preceding Scored Throws in International-level Judo Competition. *Central European Journal of Sport Sciences and Medicine*, *25(1),* 43-50. http://dx.doi.org/10.18276/cej.2019.1-05

Ito, K., Hirose, N., Maekawa, N., Tamura, M., Nakamura, M. (2015). Alterations in Kumite Techniques and the Effects on Score Rates Following the 2013 International Judo Federation Rule Revision. *Archives of Budo, 11,* 87–92.

Kiba, K., Wada, T., Takahashi H. (2022). Effect of introducing the video analysis application to women’s basketball team of K-University: Focused on the understanding of the individual technique and the team tactics. *Academic* *journal bulletin of National institute of fitness and sports in Kanoya*, *59*, 37-46. https://nifs-k.repo.nii.ac.jp/records/1203

Kitamura, T. (2021) Support programs for Japan Tennis Association's high-performance in the 2020 Tokyo Olympic games. *Bulletin of Biwako Seikei Sport College*, *19*,153-171. http://hdl.handle.net/10693/00005756

Kitazawa, T., Takahiro, F., Doi, H., Hirasawa, M., Komura, S. (2019). Effects of Reflection of Basketball Game Videos using a CSCL System Focus on Junior High School Students' Activity Recording, Ability to think and Awareness of Club Activities. *Journal of Japan Educational Research Society of the AI era*, *1*,7-12. https://doi.org/10.50948/esae.1.0_7

Maekawa, N., Ito, K., Ishii, K., Koshino, T., Yazaki, R., Tamura, M., Hirose, N. (2014). A study of validation of competitive abilities scale of judo competitors by using AHP. *Research Journal of Budo*, *47 (1)*, 1-8. https://doi.org/10.11214/budo.47.1

Miyake, K., Takezawa, T., Ito, K., Sato, S., Hirose, N. (2021). Tactical actions of nage-waza effective for scoring in judo. *Research Journal of Budo*, *54 (2)*, 103-113. https://doi.org/10.11214/budo.2110

Murata, N. (2011) Internationalization of Judo, Nippon Budokan.

Mynavi Books (2017). "GOJIRA" Analysis Software Supports Japanese Judo: Balance between "Quantitative" and "Qualitative" is Important, https://book.mynavi.jp/macfan/detail_summary/id=86615 （Last access date: 2023/11/02）.

Digital Life

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Special Issue: Digital Technology in Sports and Physical Activity
Article

The Effects of Positive and Negative Ions on esports Performance and Arousal Levels Part 2 -Testing Higher Ion Density-

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Abstract
The purpose of this study was to investigate the psychological effects of higher positive and negative ion conditions on the arousal levels of esports players during a racing game. Participants (10 males) from a collegiate esports team were the participants in the study. The effects of higher concentrations of positive and negative ions were evaluated in a randomized crossover. Each participant performed two experiments four weeks apart; two experimental environments were used: positive and negative ions filling the atmosphere (PNI) condition and a control (CON) condition. A car racing game was employed as the performance task. Arousal was measured by the two-dimensional mood scale (TDMS) and electroencephalogram (EEG). EEG was used to measure arousal. The results showed that the level of arousal in the subjective assessment and the level of arousal in the EEG were significantly higher in the CON condition for PNI. In addition, PNI performed significantly better on the game task than in the CON condition.
The present study demonstrated in positive and negative ion environments with higher concentrations than in the previous study, and the results showed higher arousal levels in subjective assessments, indicating that higher concentrations of ionic environments are beneficial for esports players.

Keywords: esports, training environment, performance, athletes, ions

1. Introduction

Successful esports athletes require psychological or cognitive skills rather than the physical skills on which athletes in traditional sports depend (Himmelstein et al., 2017) Therefore, it is important for esports athletes to train in cognitive skills and psychological skills and cognitive function. Research on training methods and environments for this purpose is also considered necessary in esports competitions. However, currently there are no established esports training methods in the field of sports science, and further research is needed. In addition to the establishment of training methods, the training environment is also important in the field of sports science. Therefore, it is necessary to study the training environment related to esports in the field of sports science.

Incidentally, an air ion is a naturally existing tiny particle, a positively or negatively charged molecule or atom in the air (Jiang & Ma, 2018). Positively charged ions are positive ions, and negatively charged ions are defined as negative ions (Yamamoto et al., 2015). Air ions, including positive and negative ions, also have certain functions such as purifying the atmosphere and deodorizing the air (Nishikawa, 2013). Some research has also been conducted on the relationship between air ions and emotions (Flory et al., 2010; Perez et al.) For example, a high-density negative ion environment was found to reduce depression. In addition, several studies have examined the relationship between

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negative ions and depression (Goel & Etwaroo, 2006; Terman & Terman, 2006; Terman et al., 1998), lower stress (Malik et al., 2010), and increased happiness (Lips et al., 1987). There are also several studies suggested that a relationship exists between positive ions environments and human emotions (Perez et al., 2013). For example, Gianinni et al. (1986) investigated the correlation between positive air ions and emotions. The results indicated that anxiety and excitement were significantly increased under these conditions. They also examined the relationship between positive ions and discomfort, irritation, and anxiety (Giannini et al., 1986; Charry & Hawkinshire, 1981). Thus, although the results of the studies are variable, there is a relationship between the environment and emotions that trigger ions.

Furthermore, negative and positive ions exist simultaneously in the natural air (Terasawa, 2002), and the effect on human biological functions when positive and negative ions are generated at the same time has also been investigated. Hagiwara et al (2021) examined the relationship between gameplay and air ions by examining the relationship between game performance and subjective and objective arousal levels in positive and negative ion environments and in controlled environments in 10 university students, The results indicated that game performance levels were higher in the positive and negative environments, as were levels of subjective and objective arousal, compared to the control environment. However, it is difficult to suggest an association with air ions based on their study alone, and as mentioned earlier, air ion research is highly skeptical and difficult to prove. Therefore, the purpose of this study was to examine arousal levels and performance in gameplay in an environment with increased concentrations of positive and negative ions, replicating the protocol employed by Hagiwara et al. (2021).

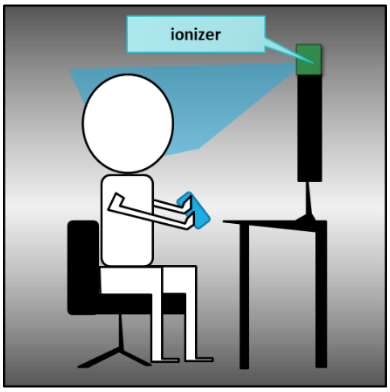

Fig.1 Position of ion exposure

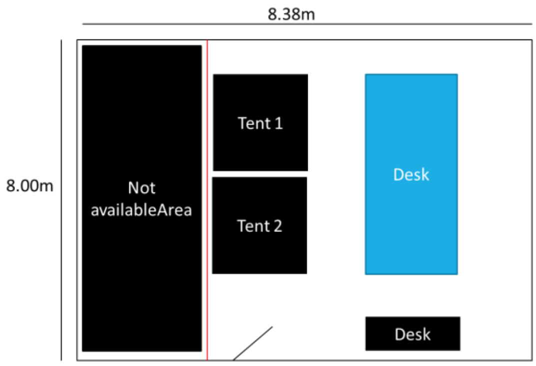

Fig.2 Laboratory Layout

2. Methods

Participants and Procedures

Participants were ten male members of a collegiate esports team. Participants were informed of the purpose of the study and completed an informed consent form prior to participation. Approval was obtained from the Institutional Review Board of the research institution. The effects of the ions environment were evaluated in a randomized, crossover, placebo-controlled, double-blind study. Each participant participated in two experiments, four weeks apart; two experimental conditions were provided: a positive and a negative ionic environment (PNI) and control conditions (CON) with the same wind speed and without ionization. In the PNI condition, a Plasmacluster® TM ionizer (Sharp Corporation) was used, and positive and negative ions (approximately 250,000 ions/cm3) were irradiated; under the CON condition, wind from the ionizer without ions was adapted at the same wind speed (wind speed: 0.43 m/sec) (Fig. 1, 2). In addition, positive and negative ions were generated by applying positive and negative high voltages to each discharge brush electrode of the ionizer to break up molecules in the air (Nishikawa & Nojima, 2001). The details of the experimental procedure are as follows (Fig.3).

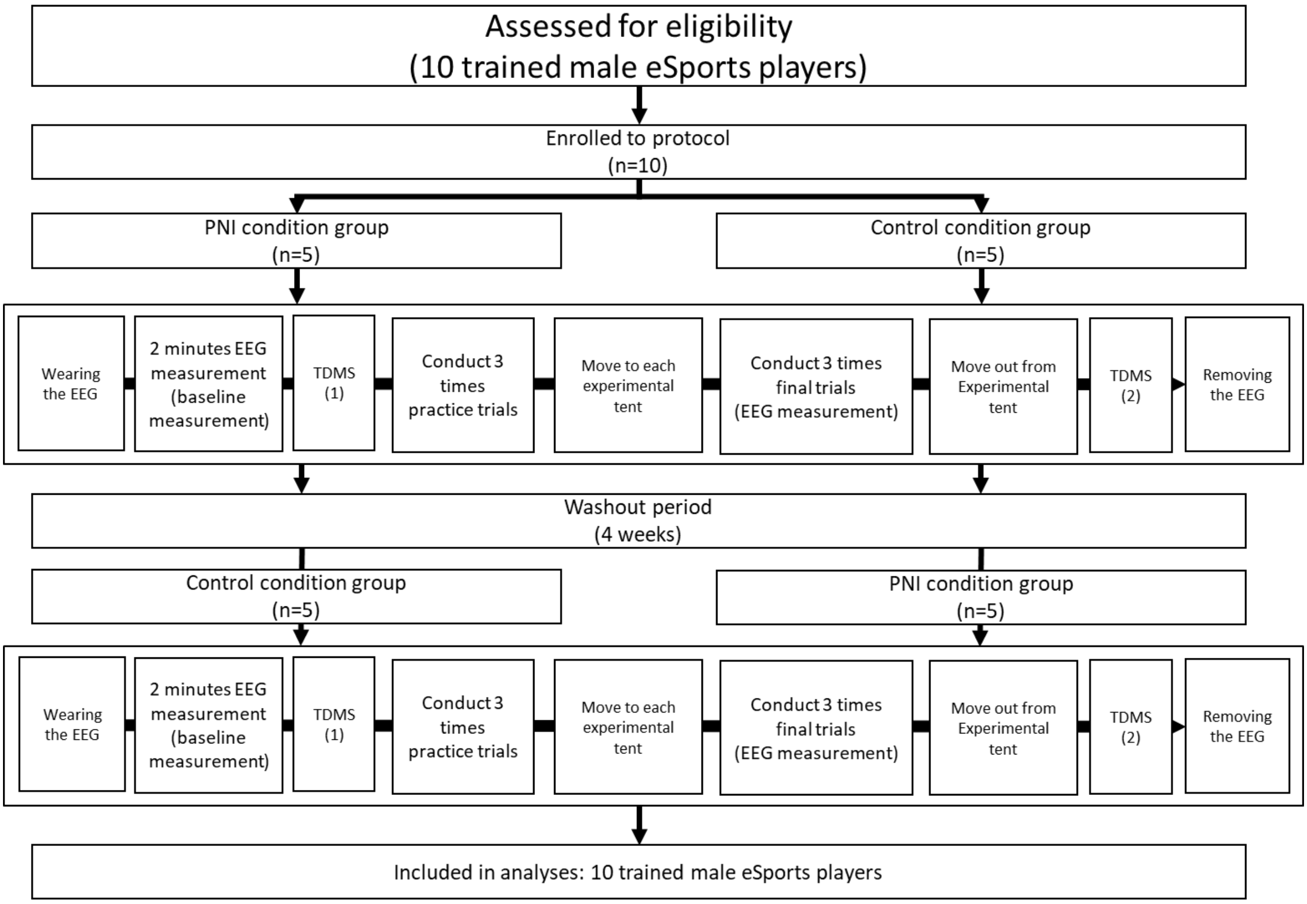

Fig.3 Flow diagram of the study design

First, participants were required to wear an electroencephalograph (EEG) for two minutes to conduct a baseline assessment of their arousal level. Then, participants completed a questionnaire to assess their arousal level before playing a racing game. Participants completed three trials as practice trials prior to the experiment in the tent. In addition, three trials were conducted as the final trial. For the performance task, participants played MARIOKART Deluxe 8. In the race mode, the setting was time attack, with three laps of the same course. The vehicle class was set to 150 cc, and participants selected a driver character. EEG was measured upon completing the task, and arousal level was measured. After the task, participants completed the questionnaire again.

Arousal level was assessed by questionnaire and EEG. The two-dimensional mood scale (TDMS) (Sakairi et al., 2013) was used to assess arousal; the TDMS consists of eight items and four factors: activity, stability, comfort, and arousal. For EEG, we employed a simple band electroencephalograph (Neurosky Corporation, Tokyo) that measures only the frontal pole 1 lobe (Fp1) as defined by the International 10-20 System, and EEG obtained from Fp1 has been found to be suitable for obtaining psychological state data (Mitsukura, 2016), Fp1 was used to estimate arousal level. The estimation method is the same as in previous studies (Hagiwara et al., 2021). The TDMS scores before and after completing the task and EEG during the task were averaged. A t-test was used to examine the difference between the PNI and CON conditions on the TDMS and EEG. For the task performance, the 3 trials prior between the PNI and CON conditions were averaged. A t-test was also performed to examine the difference between the two conditions. The IBM SPSS Statistics 25.0 software was used for the analysis, and *p* value was set at 0.05.

3. Results

3.1. TDMS

For TDMS, there was a significant tendency ($p > 0.1$) between the PNI condition ($M = 8.1$, $SD = 4.3$) and the CON condition ($M = 6.6$, $SD = 3.2$) (Fig.4).

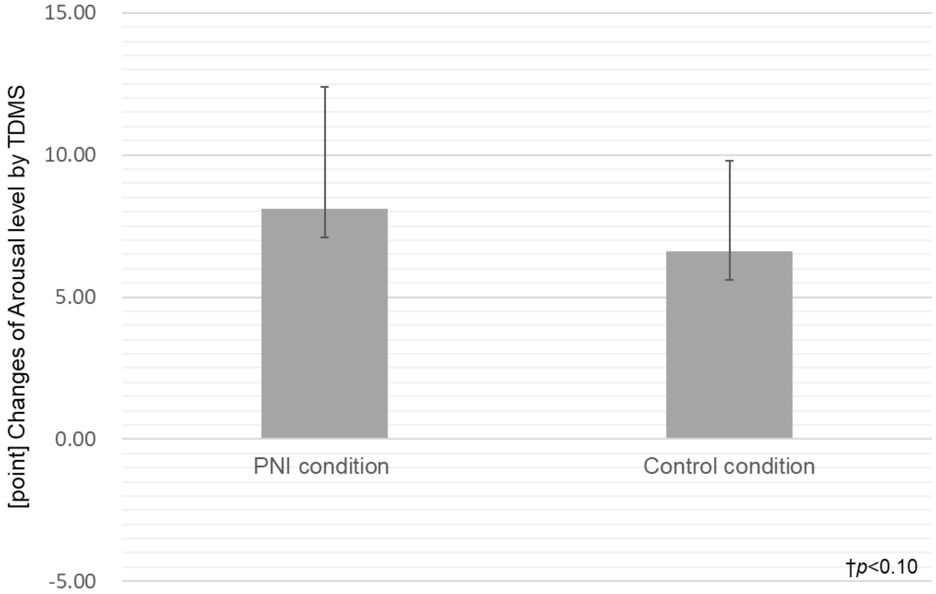

Fig.4 Arousal level by TDMS

3.2. EEG

The PNI condition (M=31.0, SD=7.3) had a significantly higher (p<0.05) change in beta band power ratio indicating arousal than the CON condition (M=10.5, SD=8.2)（Fig.5）.

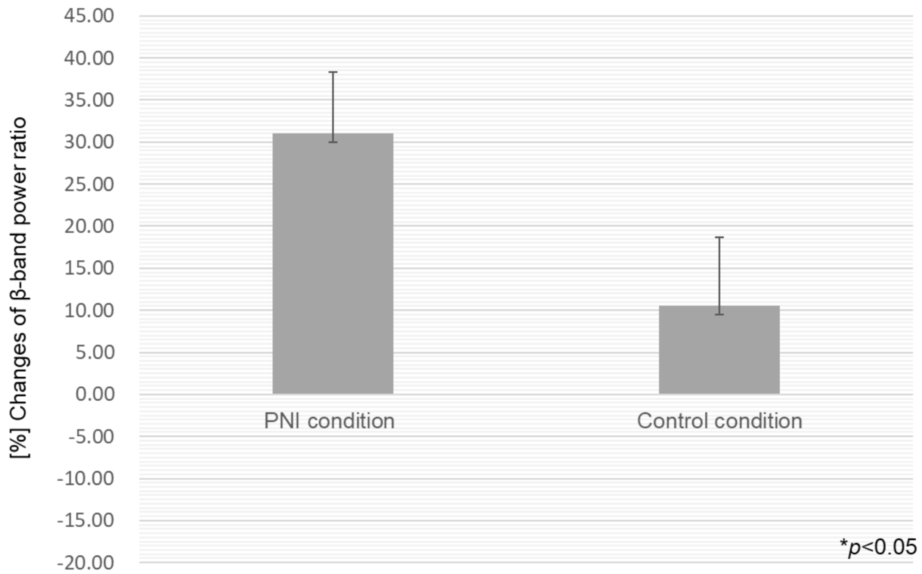

Fig.5 β -band power ratio

3.3. Racing performance

Race performance indicated that the PNI condition (M = -4.9, SD = 3.1) tended to have significantly faster time changes than the CON condition (M = -3.1, SD = 2.3) ($p < 0.1$) (Fig.6).

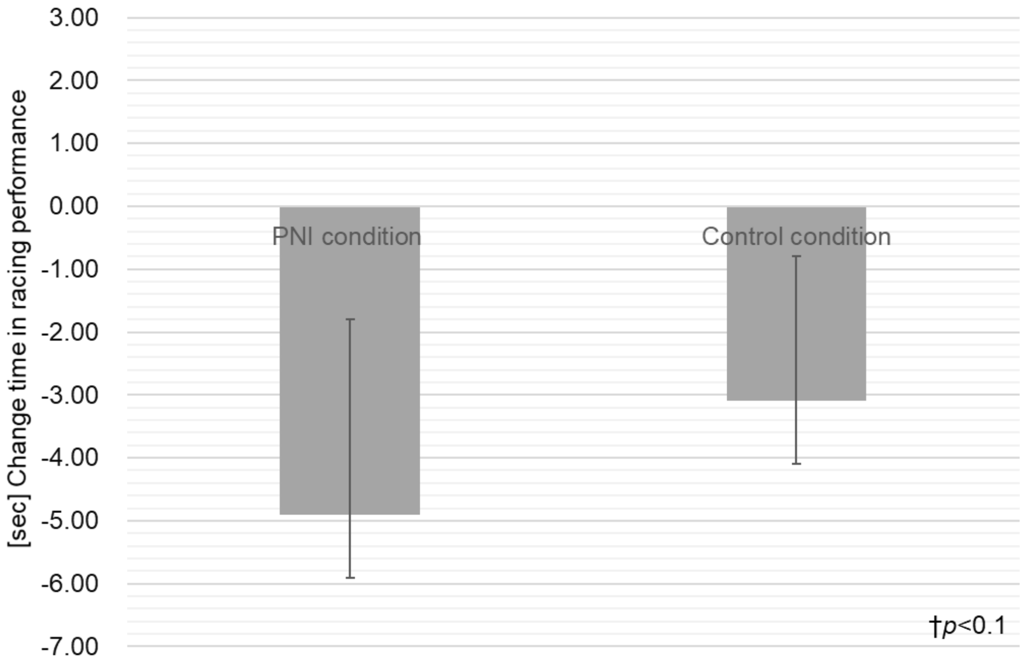

Fig.6 Racing performance

4. Discussion

The purpose of this study was to investigate the psychophysiological effects of arousal in racing game-type esports under positive and negative ionic conditions. In addition, the study was conducted in a similar experiment conducted by Hagiwara et al (2021) with an even higher ion concentration. In the present study, arousal tended to be higher in the PNI condition than in the CON condition, even in TDMS. EEG also showed that the PNI condition was higher than the CON condition in arousal. Furthermore, performance was also better in the PNI condition. how esports performance improves is of interest to researchers and esports players, and our study found that altering the environment with positive and negative ions can increase brain activation as well as improving esports performance. Furthermore, the results were even more interesting in that the effects were observed with higher ion concentrations than in the previous experiment.

Previous study examined whether the use of higher concentrations of ions differed from lower concentrations in terms of cognitive performance and physiological measurements (Wallner et al., 2015). The results showed that, although there was no difference in lung function and well-being, the higher concentrations outperformed the lower concentrations in cognitive performance. Specifically, cognitive performance was assessed by measuring reasoning ability and perceptual speed. Namely, exposure to higher concentrations of ions was shown to increase the speed of cognitive processing. In the present study, increased ion concentrations also increased subjective and biological arousal, as well as esports performance, suggesting that increased ion concentrations might be more effective.

esports is one of the fastest growing sports in the world today, and how performance could be enhanced is fascinating from many aspects. Interestingly, a recent review article focuses on the application of coaching to what practice conditions can be provided by coaches to their athletes in order to improve esports performance from a coach's perspective (Iwatsuki et al., 2021). Over the past five years, a variety of research lines in esports have emerged as researchers, coaches, and athletes search for ways to improve esports performance as in traditional sports, and environmental factors such as the use of positive and negative ions have been used in esports performance. More research will be conducted on how environmental factors, such as the use of positive and negative ions, affect esports performance.

In summary, the purpose of this study was to reexamine the effects of positive and negative ion environments on game performance and arousal levels, which had been indicated in previous studies, and the results of the present study also demonstrated that the PNI condition resulted in higher race game performance and arousal levels. It is interesting to note that the results also demonstrated a greater amount of change in subjective arousal of changing ion density.

However, to further scientifically prove the results of this study, it is also necessary to examine that what has changed in brain function. For example, additional studies of changes in cerebral blood flow in ionic environments would probably come closer to resolving the question of why game performance is better in ionic environments. Ion research is skeptical, and further experiments are needed.

5. Conclusions

The study demonstrated that esports performance and subjective and biological arousal levels were higher in the PNI condition. In addition, higher ionic concentrations were indicated to be more effective. Using the protocol implemented in a previous study (Hagiwara et al., 2021), similar findings were obtained, and given that esports performance was enhanced by increasing ion concentrations, it can be argued that positive and negative ion environments are important for the esports training environment. However, to further scientifically confirm the results of this study, it is necessary to examine what changes in brain function were observed. For example, further study of changes in cerebral blood flow in ionic environments would likely help answer the question of why game performance improves in ionic environments. Ion studies are skeptical and further experimentation is needed.

Author Contributions

Conceptualization, G.H.; methodology, G.H., H.F., M.M., S.T., H.O., and D.A.; software, G.H.; validation, G.H., and M.M.; formal analysis, G.H.; investigation, G.H., H.F, M.M., S.T., H.O. and D.A.; writing—original draft preparation, G.H.; project administration, G.H.; funding acquisition, H.F., M.M., S.T., H.O.; All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted according to the Declaration of Helsinki, and approved by the Institutional Review Board of the National Institute of Fitness and Sports in Kanoya (No.5-1, 22 April 2020).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Data Availability Statement

Not applicable

Conflicts of Interest

This study was funded by Sharp Corporation. M.M., H.F. Y.K., S.T., and H.O. are employees of Sharp Corporation.

References

Charry, J.M., & Hawkinshire, F.B. (1981). Effects of atmospheric electricity on some substrates of disordered social behavior. *Journal of Personality and Social Psychology*, *41*(1), 185-197.

Flory, R., Ametepe, J., & Bowers, B. (2010). A randomized, placebo-controlled trial of bright light and high-density negative air ions for treatment of seasonal affective disorder. *Psychiatry Research*, *177*(1-2), 101-108. https://doi.org/10.1016/j.psychres.2008.08.011

Giannini, A. J., Jones, B. T., & Loiselle, R. H. (1986). Reversibility of serotonin irritation syndrome with atmospheric anions. *The Journal of Clinical Psychiatry, 47*(3), 141-143.

Goel, N., & Etwaroo, G. R. (2006). Bright light, negative air ions and auditory stimuli produce rapid mood changes in a student population: A placebo-controlled study. *Psychological Medicine, 36*(9), 1253–1263.

Hagiwara, G., Iwatsuki, T., Funamori, H., Matsumoto, M., Kubo, Y., Takami, S., Okano, H., & Akiyama, D. (2021). Effect of positive and negative ions in esports performance and arousal levels. *Journal of Digital Life*, *1*, 2.

Himmelstein, D., Liu, Y., & Shapiro, J. L. (2017). An exploration of mental skills among competitive league of legend players. *International Journal of Gaming and Computer-Mediated Simulations, 9*(2), 1-21. http://doi.org/10.4018/IJGCMS.2017040101

Iwatsuki, T., Hagiwara, G., & Dugan, M. (2021). Effectively optimizing esports performance through movement science principles. *International Journal of Sport Science & Coaching.* https://doi.org/10.1177/17479541211016927

Jiang, S. Y., Ma, A., & Ramachandran, S. (2018). Negative air ions and their effects on human health and air quality improvement. *International Journal of Molecular Sciences, 19*(10), 2966. https://doi.org/10.3390/ijms19102966

Lips, R., Salawu, H. T., Kember, P., & Probert, S. D. (1987). Intermittent exposures to enhanced air-ion concentrations for improved comfort and increased productivity? *Applied Energy*, *28*(2), 83-94.

Malik, M., Singh, K., Singh, M. (2010). Effect of negative air ions on physiological and perceived psychological stress during computer operation. *International Journal of Environment and Health, 4*(1), 67-77. https://doi.org/10.1504/IJEnvH.2010.033035

Mitsukura, Y. (2016). KANSEI Analyzing by EEG. *The journal of the Institute of Electrical Engineers of Japan*, *136*, 687-690.

Nishikawa, K. (2013). Air purification technology of positively and negatively charged cluster ions by plasma discharge at atmospheric pressure. *Japanese Journal of Applied Physics, 89*, 164-168.

Perez, V., Alexander, D. D., & Bailey, W. H. (2013). Air ions and mood outcomes: A review and meta-analysis. *BMC Psychiatry, 13*, 29. https://doi.org/10.1186/1471-244X-13-29

Sakairi, Y., Nakatsuka, K., & Shimizu, T. (2013). Development of the Two Dimensional Mood Scale for self-monitoring and self-regulation of momentary mood states. *The Japanese Psychological Research, 55*(4), 338-349. https://doi.org/10.1111/jpr.12021

Terasawa, M. (2002). Effects of a negative ion environment on the organism. *Chemistry and Education, 50*(12), 840-843.

Terman, M. & Terman, J.S. (2006). Controlled trial of naturalistic dawn simulation and negative air ionization for seasonal affective disorder. *The American Journal of Psychiatry*, *163*(12), 2126-2133.

Wallner, T., Krundi, M., Panny, M., Tappler, P., & Hutter, HP. (2015). Exposure to air ions in indoor environments: Experimental study with healthy adults. *International journal of environmental research and public health, 12*(11), 14301-14311.

Yamamoto, D., Wako, Y., Kumabe, S., Wako, K., Sato, Y., Fujishiro, M., Yasuda, Y., Matsuura, I., & Ohnishi, Y. (2015). Positive and negative ions by air purifier have no effects on reproductive function or postnatal growth and development in rats. *Fundamental Toxicological Sciences*, *2*(3), 101-110. https://doi.org/10.2131/fts.2.101

Digital Life

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Article

Practical research on the use of digital pens in high school rugby club activities

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Abstract
Tactics play a crucial role in sports; however, coaching presents various challenges. This study examined the impact of utilizing practice notes created with a digital pen capable of simultaneously recording and playing back both audio and texts/drawings on tactical understanding. The participants were high school rugby team members and coaches. The results of a four-month practical investigation revealed that the learning experiences of tactical understanding in high school rugby teams manifested through four categories: awareness of the difficulty of tactical understanding, exploration of experiential facts, contemplation, and integration into practice. It is speculated that the utilization of the digital pen not only encouraged a deeper understanding of tactics through the formation of a meta-perspective but also led to learning strategies aimed at activating knowledge.

Keywords: Practice Notes with Voice and Drawing; Tactics Learning; Reflection.

1. Introduction

Understanding and practicing tactics play crucial roles in sports coaching (Uchiyama, 2007). Notably, tactics in ball games are considered among the most influential factors in determining athletic performance (Aida, 1994). However, teaching tactics in actual coaching situations presents several challenges. For instance, difficulties arise when applying and practicing a tactic in different situations over time, even if a player successfully practices the tactic on the field during instruction (Kitamura et al., 2014). Bruer and others have pointed out the challenge of teaching problem-solving strategies when students could solve a problem immediately after instruction but struggled to apply it spontaneously later, suggesting that knowledge might not be effectively activated (Bruer, 1993/1997).

Solutions to these issues involve repeated instruction and creating learning situations that connect students' problem-solving scenarios (Bruer, 1993/1997). Despite the Ministry of Education, Culture, Sports, Science, and Technology's (MEXT,2015) emphasis on applying learned knowledge in thinking, judgment, and expression in courses of study, practical situations often present limitations in information availability. Due to space and time constraints, coaches' instructions on tactics tend to be one-sided and temporary, possibly failing to achieve sufficient understanding (Ichimura et al., 2009).

In response to the aforementioned challenges in teaching tactics, researchers have emphasized the importance of fostering understanding through repetitive learning and utilizing players' own practical experiences as learning materials (Matsuo and Maruno, 2007; Uesaka, 2010; Kikukawa and Saiki, 2013; among others). One strategy for supporting learning through repetition is the integration of information and communication technology (ICT) equipment. Numerous studies have highlighted the effectiveness of learning using ICT equipment. Murakami (2020) reported that incorporating ICT into basic nursing education was effective in enhancing learning motivation.

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Nakamura et al. (2019) found that the use of ICT in science education can be effective in developing qualitative abilities. In the field of sports, Nakajima et al. (2022) suggested that ICT could be an effective teaching tool for skill improvement. Shigeta (2014) reported that ICT-enhanced classes, such as those employing flipped learning, were expected to have positive educational effects. Kitamura et al. (2013, 2014) discovered that the use of digital pens in learning, particularly among high school and university students, plays a crucial role in facilitating reflection and understanding.

Despite the series of studies conducted, there remains a noticeable gap in the research concerning the effects of ICT device utilization on learners' learning processes, including how these devices influence the way learners acquire knowledge. Moreover, there is a lack of sufficient practical research grounded in theoretical frameworks on the application of ICT devices in real sports practice scenarios and their potential to enhance players' learning experiences. Specifically, comprehending instructional content solely during practice is challenging, emphasizing the importance of the repetitive learning of tactics outside practice situations within the context of problem-solving scenarios. This is essential for achieving a profound understanding of instantaneous decision-making during gameplay. Consequently, there is an urgent need for research that establishes the connection between understanding and practice.

The primary objective of this study was to elucidate the impact of using a digital pen for tactical instruction on players' understanding of tactics. Specifically, this study utilized a digital pen equipped with a built-in IC recorder capable of synchronously capturing voices and handwriting (Echo Smartpen). During the post-practice review, the coach employed a digital pen to explain the tactics, and the players subsequently reviewed the instructions before the next day's practice. This study aimed to discern how tactical instruction delivered through digital means, in conjunction with on-field guidance, influences players' comprehension of tactics and shapes their overall learning experiences.

Given the study's focus on analyzing internal factors within the coaches and players, particularly the nuances of their experiences related to tactical understanding, a qualitative research method was deemed appropriate (Kitamura et al., 2005) and adopted as the methodology for this investigation.

2. Methods

2.1. Participants

This study involved 45 participants from a public high school rugby club, comprising 39 players, 4 managers, and 2 coaches.

2.2. Procedure

Figure 1 shows an overview of tactical learning using digital pens. After practicing on the ground, the coaches create a notebook with audio, text, and drawings using digital pens to explain the issues during practice and points for the next practice session. The notes are shared via Dropbox, and the players watch the notes at home or school before the next practice session using a smartphone or PC. This cycle of tactical learning through practice and reflection is repeated. Figure 2 shows a tactical practice note created using a digital pen.

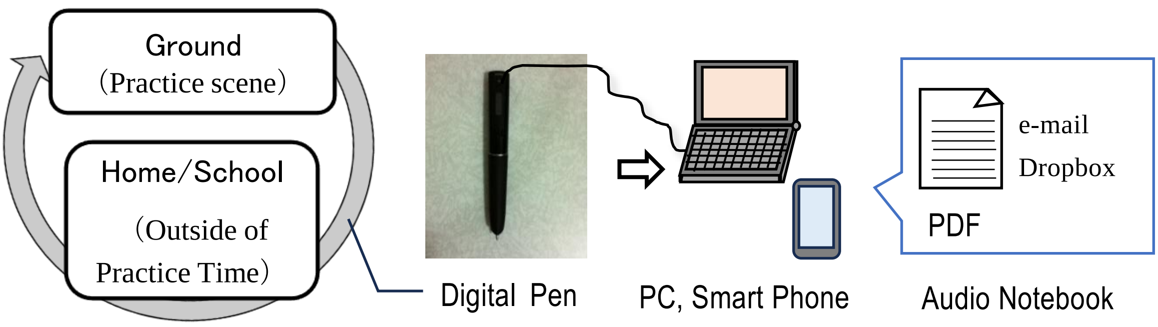

Figure 1. Overall view of tactical learning with digital pens

- Digital pen developed by Livesclibe, a Gakken Education Publishing company
- Capable of synchronously recording text and voice
- Capable of managing text and voice data on a PC

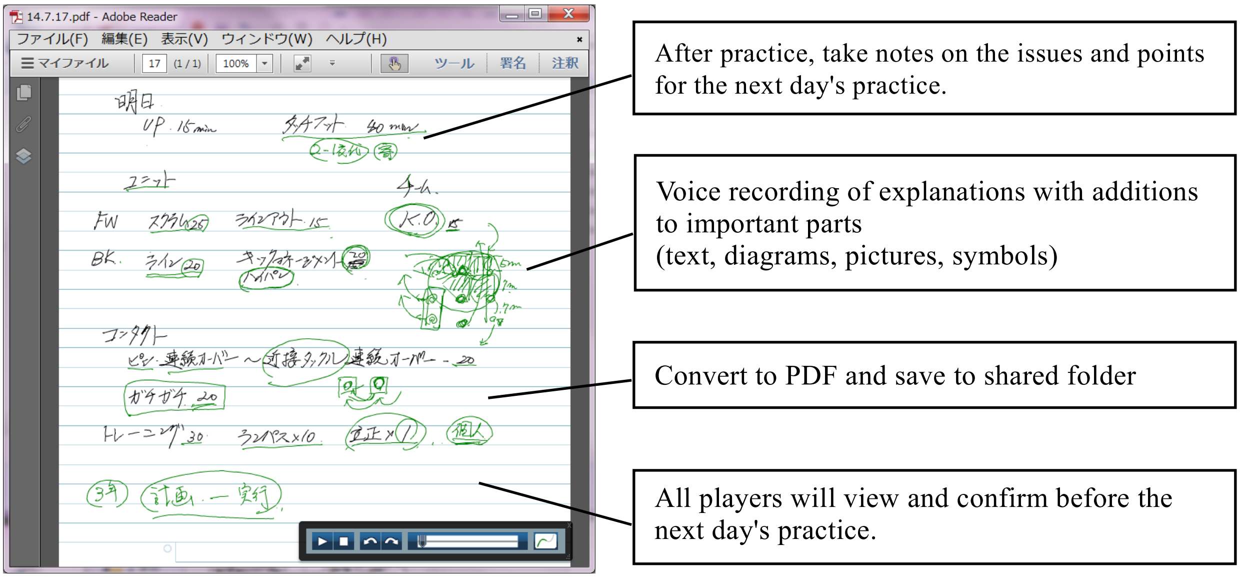

Figure 2. Composition of tactical practice note created using digital pen

The survey was conducted over a four-month period, from October 20XX to January 20XX. Prior to the survey, the functions and uses of the digital pen used in the study were explained. All participants were then asked to use the pen freely for two weeks to ensure that they were familiar with its use.

2.3. Data collection: Use of digital pens

After a practice session, the two coaches made notes using a digital pen. They wrote explanations in a notebook while speaking aloud and recorded their voices. The notes were saved as PDF files and stored in a Dopbox folder shared by the members of a rugby club. All club members looked at the PDF notes before the next day's practice session, reviewed them, and confirmed the key points in their tactics. Figure 3 shows an example of an actual tactical practice note recorded using a digital pen with synchronized voice and handwriting.

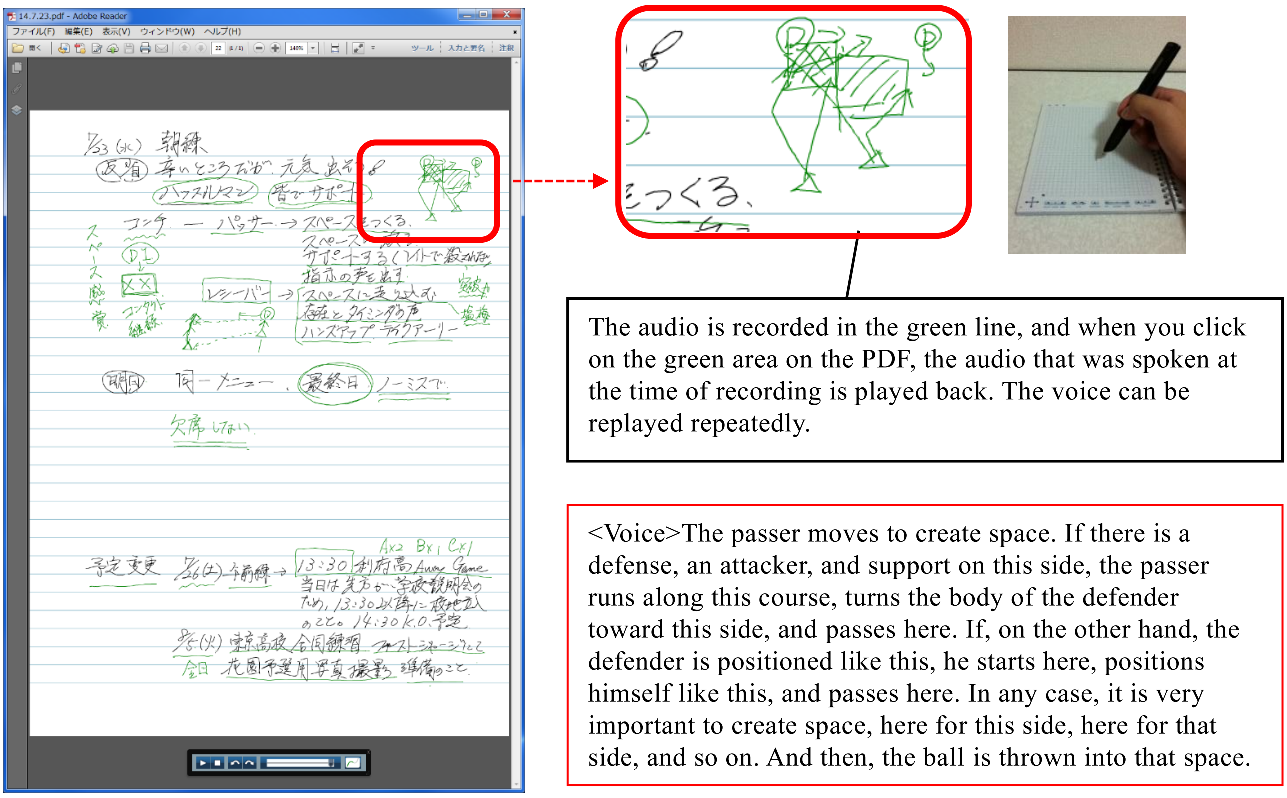

Figure 3. Example of a tactical practice note with digital pen

2.4. Data collection: Interview survey

Data were collected every month through semi-structured, in-depth, open-ended interviews using stimulated recall with the coaches and all team members based on the contents of their notebooks and audio recordings. We conducted semi-structured interviews. The interviews were conducted retrospectively, focusing on the coaches' intentions, thoughts, feelings, and perceptions regarding what was described in their notes. Interviews with players and managers were conducted before, during, and after the practice sessions, focusing on their experiences with the digital pen.

2.5. Data analysis

The voice data obtained from the interviews were converted into text, and hierarchical categorization was conducted based on the qualitative data analysis methods of Côté et al. (1993) and Patton (2002), with multiple researchers involved in the analysis process.

2.6. Credibility and certainty

The quality of the study was evaluated according to authenticity (reality of the data) and certainty (reliability of the data and procedures).

First, to concretely describe the details of the participants' experiences, a survey was conducted on their practice situations and interviews were conducted concerning their digital pen descriptions. Second, interviews were conducted in a semi-structured manner to standardize the questions posed to various participants and ensure the reliability of data collection. Third, the analysis was based on written notes and audio recordings, treating the content of the participants' narrative descriptions as the focus of the analysis, thereby ensuring data reliability. Fourth, the data analysis process was shared between several experts, and the analysis was conducted through multiple discussions to ensure reliability.

3. Results and Discussion

An analysis of 165 meaning units (semantic content elements) revealed that the learning experience associated with the use of digital pens for tactical instruction in rugby could be categorized into four themes: representation of disincentives, exploration of experiential facts, thinking through ideas, and incorporation into practice. The following provides a detailed description of each category.

Table 1. Hierarchical Category and Key Utterance Lists

Category	Subcategory	speech example
Representation of disincentives	-Difficult to understand in practical situations -I cannot remember -Chain of Unknowing	It is so difficult that I only understand about half of what is going on in that scene.
Exploration of experiential facts	-Multifaceted information from text, drawings, and sound -Repeatable listening -Use of temporal and spatial convenience -Cues to deeper and broader explanations	You can confirm points that are not clear after hearing them once by listening to them repeatedly.
Think through the ideas	-What went wrong? -Just what I wanted to ask -Looking for the point -What was the point?	Listen to what the teacher emphasized and look back to see what mistakes you made.
Incorporation into practice	-Understanding of the meaning of their own movements -Awareness of relationship with other players -Relation to acquired skills	See yourself from the outside during practice and visualize what you need to do next

3.1. Representation of Disincentive

This category comprises subcategories such as “difficult to understand in practice situations,” “I cannot remember,” and “chain of unknowns.” The participants shared their experiences of confusion during practice sessions regarding the tactics explained by the coach, including challenges such as not understanding them immediately, difficulty comprehending them, struggling to remember them even after practice, and persistently not grasping them. As they verbalized these difficulties in understanding tactics during practice, they gained awareness of various factors hindering comprehension — factors that they had vaguely sensed.

One player elucidated a problem in tactical practice: *“During practice on the ground, the teacher explained to me what was happening.” (Player T)*

Player A highlighted the challenges faced during tactical practice: *“The teacher explains it to us on the field during practice, but it is so difficult that I can only understand about half of what he says.”*

Player J described an experience that was challenging to understand even upon recall: *“During practice, I just kind of get through it by imitating everyone else. When I go home and try to remember and understand, I often forget things, and what I hear and see during practice is limited, so I often don't understand.”*

One player highlighted the challenge of entering the next practice session without a full grasp of the tactics, resulting in insufficient practical application. *“Tactics are difficult. Even in practice, I think I understand when I am told, but when I actually play, I don't understand. I would go back to practice the next day without really understanding what was going on. In fact, I often couldn't use the same moves in games.” (Player F)*

The following three categories illustrate how digital pens offer solutions to these issues.

3.2. Exploration of Experiential Facts

This category comprises subcategories such as “multifaceted information from text, drawings, and sound,” “repeatable listening,” “use of temporal and spatial convenience,” and “cues to deeper and broader explanations.” These subcategories were established to capture awareness of the search for facts about the experience occurring during the practice sessions while maximizing the functional convenience found in using a digital pen.

One player, highlighting the advantages of multifaceted information, remarked, *“The practice notes written with a digital pen are easy to understand because you get a variety of information through text, pictures, and voice.” (Player B)*

Another player emphasized the benefit of repeatedly listening to the video for confirmation: *“I can't understand a point after hearing it once. I can listen to the notes repeatedly to check points that I couldn't understand just by listening to them once.” (Player H)*

In addition to the convenience of the digital pen, the players expressed appreciation for the coaches’ detailed explanations about the device. They valued the coaches’ ability to delve deeper into the points covered during practice sessions and craft instructional content for problematic situations. One player articulated this sentiment: *“The teacher's explanations were very helpful. His insights into mistakes made during practice, including discussions on their causes, potential outcomes, and countermeasures, enhanced our understanding of the situations in depth.” (Player A)*

In this manner, players actively seek clues about the facts of their actions, including information about the surrounding situations, which is fundamental to tactical understanding. Digital pens have demonstrated functionality in supporting the exploration of experiential facts from multiple perspectives.

3.3 Thinking through the Ideas

This category consists of subcategories such as “What went wrong?,” “just what I want to ask,” “looking for the point,” and “what was the point?” This signifies the experience of seeking answers to various questions that arise as preconditions for understanding, such as the “how” and “why” questions. This process occurs while watching practice notes, reflecting on one’s own experiences, comparing them with the coach’s insights, and relieving them.

One player articulated the experience of new questions arising as he explored the causes of his mistakes: *"I listened to what the teacher emphasized. As I listen to what the coaches emphasized and look back to check my mistakes, I contemplate why those mistakes happened, and then I ponder possible solutions." (Player D)*

One player highlighted a situation in which new questions arise, expressing, *"While I listen to the teacher's explanations, I have new questions, such as why and how I should move. I am now more aware of the issues that need to be addressed in the next practice session." (Player U)*

In this manner, we observed a shift in the players' tactical understanding. It moves beyond comprehending the content of an explanation to adopting a learning method that includes strategies for deeper understanding. This involves reflecting on their own movements and thoughts as well as generating new questions for further exploration during the next practice session.

3.4. Incorporation into Practice

This category consists of subcategories such as "understanding the meaning of their own movements," "awareness of relationships with other players," and "relation to acquired skills." It aims to illustrate how the use of digital pens enables players to objectively grasp their movements and thoughts. This, in turn, materialize their awareness, allowing them to connect their understanding of tactics to practice from a meta-viewpoint that provides a bird's-eye view of the entire ground, including other players.

One player described the awareness of having a bird's-eye view of their own movements on the ground: *"When I am contemplating tactics while watching the practice notes, I become more conscious of observing myself on the ground from an external perspective during the next practice. This heightened awareness extends to the movements of other players, enabling us to form an image of what we should do next." (Player W)*

One player highlighted how understanding tactics from a meta-perspective has enhanced his comprehension of the practice itself, prompting him to set goals for the next sessions. *"Since I started using the digital pen, I can better understand the very meaning of the exercises in our tactical training. I can discern why the practice is necessary, what I can achieve through it, and how it contributes to the game. Consequently, I am able to set my own goals for the next practice session." (Player Y)*

In this manner, the use of a digital pen creates a meta-viewpoint for perceiving tactics, facilitating deeper understanding, peripheral thinking, awareness of the meaning of practice, and goal setting. This underscores the importance of incorporating this understanding into practical applications.

4. General Discussion

This study aimed to clarify how the use of digital pens for tactical instruction in a high school rugby team affects players' understanding of tactics. These efforts extend beyond merely investigating the effects of using ICT devices in sports to improve practice efficiency. This study explored the educational value of ICT devices by examining their influence on the quality of learning itself, including changes in the way learners learn and alterations in their perspectives on learning.

Figure 4 shows the relationship among the four categories: representation of disincentives, exploring experiential facts, thinking through the ideas, and incorporation into practice, derived from the analysis of participants' learning experiences, as a model for understanding tactics using a digital pen. The digital pen-enhanced learning space is represented by a circle within which the four categories are positioned in a circular fashion. Each of the four categories is located in four quadrants formed by two axes: the event/reflection and diffusion/convergence axes. The learning of tactics was placed at the center of these cycles.

The difficulty in understanding tactics, initially focused on the practice situation, becomes more diffused through the use of a digital pen. This allows the viewpoint to be directed towards one's own movements and cognition, leading to the development of thinking in a more diffused manner. The perspective of taking a meta-view of the situation forms an intention to perceive tactics from multiple perspectives and understand the situation from various angles. This is thought to activate knowledge, enabling participants to relate their learned knowledge more concretely to their practice.

Regarding the cycle of learning, a coach felt that the strategy of tactical understanding using a digital pen was effective, and stated, *"Coaching with a digital pen is becoming a very effective tool for our team, which has a large time constraint."* In particular, he highly appreciated the fact that he could focus on issues found during practice, organize problems about what was happening, and explain the causes and countermeasures from a bird's-eye view using drawings. He said, *"If we can develop detailed instruction of skills with drawings and audio, tactical understanding will become deeper."*

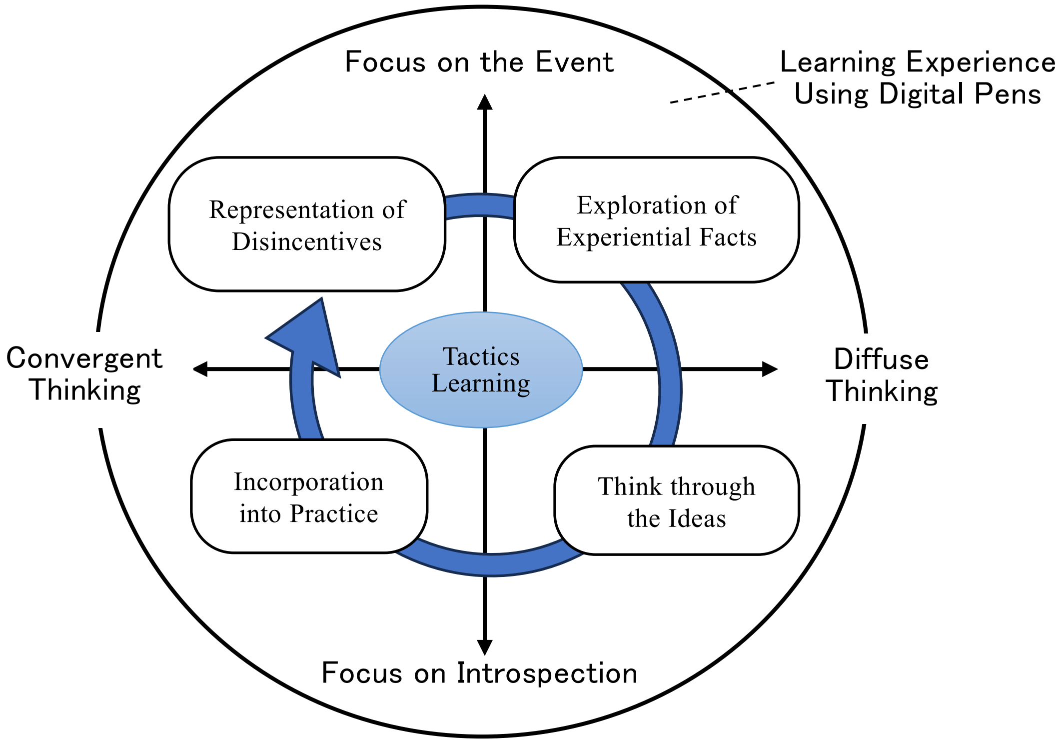

Figure 4. Circular model of tactics learning using digital pens

In addition to facilitating the understanding of individual players, the exchange of opinions among players regarding the content of their understanding stimulates communication, allows them to reconcile their understanding, and facilitates the development of practice in line with the coaches' intentions. This can be confirmed as a significant result of the tactical understanding using a digital pen.

5. Conclusion

Through the use of notebooks created using a digital pen that can simultaneously save and play back audio, text, and drawings, it became clear that the learning experience of tactical understanding in high school rugby clubs is indicated by four categories: representation of disincentives, exploration of experiential facts, think through the ideas, and incorporation into practice. The use of digital pens creates a meta-viewpoint from which to perceive tactical practice, enabling a bird's-eye view of the movements of all members, including oneself. This facilitates a deeper and more developed understanding of tactics, clear goal setting for the next practice session, and, consequently, an improvement in the quality of practice. Moreover, there was a shift in players' learning strategies towards activating knowledge.

For future research, it is necessary to verify how this method can be applied to sports other than rugby. Further studies are required to determine how the method can be applied not only to the study of tactics but also to the broader study of sports.

Author Contributions

Conceptualization, K.K.; methodology, K.K.M. and T.N.; validation, K.K., Y.M. and T.N.; qualitative data analysis, K.K. and Y.M.; investigation, K.K. and Y.M.; resources, T.N.; writing—original draft preparation, K.K.; writing—review and editing, K.K.; visualization, Y.M.; supervision, T.N.; project administration, K.K.N.; funding acquisition, T.N

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Institutional Review Board Statement

The study was conducted according to the Declaration of Helsinki.

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Conflicts of Interest

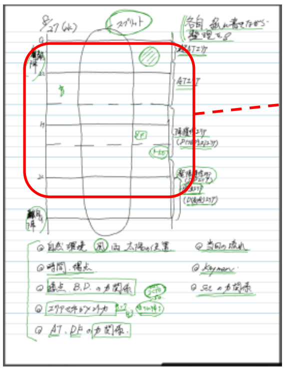
The authors declare no conflict of interest.

Acknowledgments

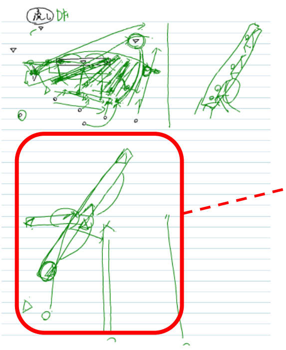
This study builds on and enhances the authors' 2014 presentation at the 65th Conference of the Japan Society of Physical Education and Sports.

Appendix

Example drawing and audio of tactical practice notes recorded with a digital pen.



<Voice>For example, what should we do if it were a scrum here? What options are there, and in what order should they be chosen? If it is a lineout here, where should it be released and what should it do? The first thing to consider is the natural environment. Especially the wind. Next is the relationship between time and score. This is an obvious factor to consider. Then there is the flow of the game on that day. If you are making mistakes, and they are continuing, what do you choose to do? Then there is the position of the opponent's key players. For example, if you have a fullback who is a very good attacker, and you just kick a long kick into the fullback's defensive area, that just provokes a counter. This will only provoke a counter. This is a very bad choice. So what should you do? So, let's assume where the key players are, especially when we consider the attacking and countering ability of the back-three.



<Voice>Now, if I cut out a certain part of that sink defense of yours, for example, it very often looks like this. The surface has already collapsed, and the situation is like this. The attack against it, for example, is dangerous here. If this person doesn't get out, space is created here, and he runs into this space, he is forced to change the direction of his body like this. As soon as he changes direction, a pass is released, and there is nothing the defense can do about it. So it is very important to be here. So, it is very important to be here, to push out like this, and to keep this side of the field unbroken. So the burden is on the person on the inside. However, he is a shadow defenseman, so the number of tackles itself should not be that many.

References

Aida, H. (1994). A study on the development of tactics in ball games. *Journal of Sports and Exercise Science, 7*, 24-32.

Bruer, J.T. (1997). Jugyo ga kawaru (Matsuda and Mori Trans.). Kyoto: Kitaooji Press. (Original work “School for thought: a science of learning in the classroom” published 1993).

Côté, J., Salmela, J. H., Baria, A. & Russell, S. J. (1993). Organizing and interpreting unstructured qualitative data. *The Sport Psychologist, 7*(2), 127-137.

Kikukawa, M., & Saiki, T. (2013). Methods for Effective Teaching and Meaningful Learning in Medical Education II. *Medical Education, 44*(4), 243-252.

Ichimura, S., Nakamura, R., & Inoue, A. (2009). A Multimedia CSCL system for learning sports skills and strategies. *IPSJ SIG Technical Report,* 1-12.

Kitamura, K., Saito, S., & Nagayama, T. (2005). How do Expert Coaches Enhance Athletes’ and Team Performance? *Japanese Journal of Sport Psychology, 32*(1), 17-28.

Kitamura, K., Matsuura M., & Nakajima, T. (2013). Qualitative Analysis on Implementation and Effects of SMARTPEN for a Freshman Class. *Proceedings of the 29th Conference of Japan Society for Educational Technology,* 607-608.

Kitamura, K., Matsuura M., & Nakajima, T. (2014). Practical Application of Tools for Better Understanding of Practice Content in High School Rugby: A Practical Study with Digital Pen. *Proceedings of the 65th Conference of Japan Society of Physical Educational and Sports,* 258.

Matsuo, G., & Maruno, S. (2007). How does an Expert Teacher Create Lessons so that Children Think Subjectively and Learn from Each Other? *Japanese Journal of Educational Psychology, 55*, 93-105.

MEXT. (2015). Aim of the New Courses of Study. https://www.mext.go.jp/b_menu/shingi/chukyo/chukyo3/siryo/attach/1364316.htm

Murakami, D. (2020). Information and Communication Technology Utilization and Impact in Basic Nursing Education: A Literature Review. *Traditional Medical Nursing Cooperative Research, 1*(1), 72-81.

Nakajima, M., Tahara, S., Suzuki, H., Nagano, T., & Kohtake, N. (2022). Improving Tag Rugby Skills through Direct and Video-Based Instruction. *Sports Industry Studies, 32*(1), 19-28.

Nakamura, D., Yamane, Y., Nishiuchi, M., & Unzai, H.(2019). Meta-analysis of Effectiveness of Technology in Science and Mathematics Class. *Science Education Research, 43*(2), 82-91.

Patton, M.Q. (2002). Qualitative evaluation and research methods (2nd ed.). Newbury Park, CA: Sage.

Shigeta, K. (2014). Flipped Classroom: Educational reform utilizing information technology. *Journal of Information Processing and Management, 55*(10), 677-684.

Uchiyama, H. (2007). Elucidation of a method for study on sports tactics. *Japanese Journal of Physical Education, Health, and Sport Science, 52*,133-147.

Uesaka, Y. (2010). How learning strategy use transfers across different school subjects: A case study on promotion of spontaneous use of “lesson induction”. *Japanese Journal of Educational Psychology, 58*, 80-94.

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Article

Transferability of Multiple Object Tracking Skill Training to Professional Baseball Players' Hitting Performance

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Abstract
This study aimed to determine the effects of multiple object tracking (MOT) skill training on elite baseball players. Baseball demands athletes to exhibit a high level of dynamic movement and quick and accurate situational judgment in multiple situations, including offense, defense, and base running. However, current research has not clarified whether the effects of MOT skills training are transferable to baseball performance. We investigated whether MOT skill training influenced baseball hitting performance before and after the intervention. Twelve players from a Japanese professional baseball team participated, and the intervention spanned approximately five months. The MOT skills of all players significantly improved (n=12). Additionally, we assessed the changes in hitting performance following MOT skill training. The results revealed a significant trend toward an improvement in the zone contact rate, zone swing strike rate, and outside swing strike rate in the breaking ball condition, such as the curveball and slider, indicating a large effect size (n=6). Further research across various competition levels is necessary to explore the transfer effects of MOT training on baseball-specific parameters.

Keywords: Multiple object tracking (MOT); Baseball performance; Task transfer; Cognitive function; Elite athletes.

1. Introduction

Tracking multiple objects moving in the visual field is called multiple object tracking (MOT). Pylyshyn and Storm (1988) have reported a continuous and dynamic visual attention mechanism using MOT tasks. In the MOT paradigm, a set of visually indistinguishable objects (typically 6-10) is presented on a screen (2D or 3D) with designated target objects to be tracked (usually 3-5). The participants tracked these designated objects for a defined period and identified the tracked objects once they stopped moving. Two methods are commonly used: the mark-all method, in which all the specified tracked objects are identified, and the probe-one method, in which one selected object is identified as a tracked object. The difficulty of the MOT task can be adjusted by varying the number of tracked and disturbed objects

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and the speed of object movement. In the psychophysical field, ongoing research includes attentional process models, as reviewed by Meyerhoff, Papenmeier, and Huff (2017), pertaining to tracking theory during MOT implementation.

For instance, in team sports, elite athletes require not only physical prowess but also essential visual skills (sports vision) and perceptual-cognitive skills, such as anticipation and decision-making. Notably, perceptual-cognitive skills are trainable, and it is assumed that honing skills specific to the sports domain enhances situational judgment, thereby improving overall performance. Faubert and Sidebottom (2012) have developed a 3D-MOT-specific perceptual-cognitive skills training paradigm called Neurotracker (CogniSens Athletics Inc., henceforth NT) and use it to train the perceptual-cognitive skills of athletes in open-skill disciplines. MOT is necessary in open-skill disciplines and is important in advanced visual processing in situations in which multiple objects are in motion, according to their research. Mahncke et al. (2006) have suggested that MOT can be trained in neuroscience research. Therefore, because the MOT paradigm can be viewed as the ability to achieve a desired behavior, MOT is treated as a skill in this study.

MOT skill training has been effective in enhancing cognitive function by stimulating multiple brain pathways involved in decision-making (Goodale & Milner, 1992). Parsons et al. (2014) have further demonstrated that the NT is implicated in sustaining attention, working memory, and visual information processing speed, among other cognitive functions. Garland and Barry (1990) have asserted that perceptual-cognitive skills are pivotal for enhancing the performance of sports competitors in complex and dynamic environments. Therefore, the enhancement of perceptual-cognitive skills through MOT skills training may contribute to improvements in sport-specific performance.

A study examining the effects of MOT skills training has found a 1.4-fold improvement in visual tracking speed among college baseball players following a three-week training program consisting of 12 NT training sessions (Furukado, Akiyama, Sakuma, Shinriki, Hagiwara, & Isogai, 2019). Thus, while previous studies have described the feasibility of MOT skills training, few have demonstrated that MOT skills improvement is a significant factor in superior performance (Faubert & Sidebottom, 2012).

In recent years, a small number of studies have explored how the transfer effect (transferability) of MOT skill training influences sport-specific performance. For example, Mangine et al. (2014) have investigated the relationship between MOT skills and stats in 12 professional basketball players, using data from one season. Results show that MOT skills were closely related to basketball performance, with significantly strong positive correlations between turnover and assist-to-turnover ratios.

However, in baseball, the subject of this study, it is not clear whether the effects of MOT skill training are transferable to performance. In baseball hitting situations, batters begin preparing to hit the ball even before the pitcher releases it. Within approximately 150 milliseconds after the ball is thrown, they must identify the pitch type and course, predict the trajectory of the ball, and decide whether to hit or not hit the ball by moving the bat to that position (Adair, 1995). Because MOT skills can reflect attentional resource capacity (Tullo, Faubert, & Bertone, 2018), mastering them could aid batters in efficiently processing the temporal and spatial aspects of the hitting situation. This study thus examines the relationship between MOT skills and baseball hitting performance.

Faubert and Sidebottom (2012) have noted that it is challenging to ascertain the degree of improvement in ability after sustained long-term MOT skills training and have reported no ceiling effect, even after 40 sessions in the MOT task. Therefore, this study aimed to determine the effect of MOT skill training over a five-month intervention on baseball hitting-specific statistics among players in the Japanese professional baseball team.

2. Methods

2.1. Test Participants

Thirteen participants were members of the Eastern League, a Japanese professional baseball team. One participant withdrew from the experiment, resulting in 12 participants. The participants had no previous MOT skills training, had static visual acuity of at least 1.0 including correction, and met the experimental entry requirements for normal color vision and visual function (age: 22.25 ± 2.74, height: 177.92 ± 5.71, bodyweight: 80.50 ± 7. 59, mean value ± Standard Deviation). Three participants were pitchers; one was an infielder; four were outfielders, and four were catchers.

2.2. Procedures

MOT skill measurements were administered to 12 participants before the intervention. Next, MOT skill training was conducted for the duration of the five-month intervention period, but the frequency of NT training was not controlled by the players. Finally, as with the pre- and post-training measurements of MOT skills, the pre- and post-training data were compared. The CORE mode included in the NT application was used for MOT skill measurements, and the average of the three session scores was used, following a previous study's method (Parsons et al., 2014).

2.3. Intervention method

1) Training Task (NT): Participants wore active 3D glasses in a room and sat in front of a monitor. An immersive cube was displayed on the monitor and eight yellow spheres (objects) were randomly placed inside the cube (Figure 1a). First, four of the eight objects were randomly selected. The four selected objects were highlighted with a white ring for a period of two seconds (Figure 1b). Subsequently, all objects reverted to yellow, became indistinguishable from other objects, and moved randomly within the cube for eight seconds, repeatedly colliding with the walls and other objects (Figure 1c). Immediately after the objects came to rest, they were randomly assigned a number from one to eight, and the participants responded by identifying the numbers of the four objects they were assigned to track and typing them into the wireless keyboard (Figure 1d). The four correct objects were then provided feedback with an emphasized white ring and shown to the participant (Figure 1e). This sequence of events constituted one trial for a total of 20 trials (i.e., one session). Each trial was conducted using the staircase method (Levitt, 1971). The speed of object movement increased if the participant correctly selected all four objects in the previous trial and decreased if the participant selected any one of the four objects incorrectly. The movement of the object increased in 0.05 log increments for the correct answer and decreased in the same manner for the incorrect answer. The staircase method was interrupted after eight reversals and the average velocity of the last four reversals was used to calculate the final speed threshold. Several types of NT training modes are based on the CORE-mode described above.

During the training period, the participants were not limited to the CORE mode; they also incorporated the OVERLOAD mode. The OVERLOAD mode is characterized by the object movement speed being fixed to its current NT baseline score (the average of the last three CORE mode results). The DUAL task mode, in which another task is performed simultaneously while performing the NT, was also utilized, including standing, one-legged standing, squatting, and BOSU-ball tasks.

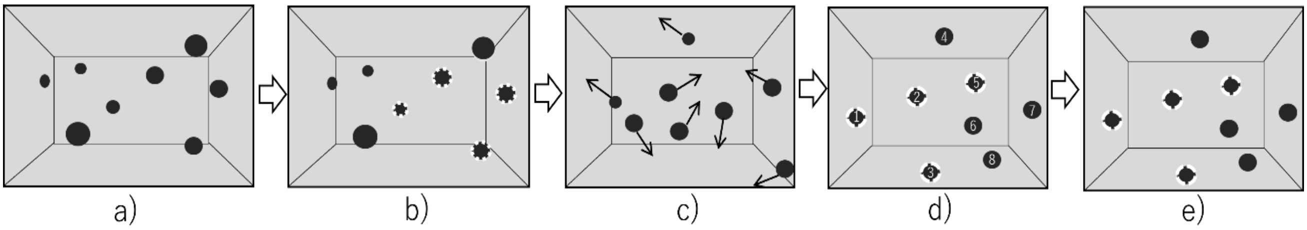

Figure 1. Detailed protocol for NT tasks.

2) Training conditions: One session of NT took approximately eight minutes, and the participants were limited to a maximum of three sessions per day during the intervention period. The basic training mode of NT was the CORE mode; however, the OVERLOAD and DUAL task modes were also used according to the training progress of each athlete. There were seven NT times (1. after waking up, 2. before departure, 3. before practice, 4. during practice, 5. after practice, 6. after returning home, and 7. before going to bed), and the participants were asked to enter the appropriate time after the session. In addition, sufficient rest time was provided between sessions.

3) Hitting performance before and after training: After discussions with the coaches of the teams, we determined the indicators used in the analysis of baseball hit performance. Hitting statistics were collected during the Eastern League season, specifically four months prior to the start of NT training and five months after the start of NT training. Statistical data were classified into two categories based on the pitch conditions of the opposing pitcher: the straight pitch (fastball and sinker) and the breaking pitch (curveball and slider). The following four indices (percentages) were used to determine hit performance.

a) Zone contact: The percentage of batted balls (including foul balls) that occurred when the batter swung. The number of contacts was calculated by subtracting the number of swinging strikes from the total number of swings.
b) Zone-swing strike: The percentage of all pitches thrown in the strike zone that resulted in strikes when the batter swung at them.
c) Outside swing: The percentage of batters who swung at pitches thrown outside the strike zone. This was calculated by dividing the number of pitches in the ball zone by the number of swings in the ball zone. Note that this indicator does not imply swinging away.

d) Outside-swing strike: The percentage of cases in which a batter swung at a pitch thrown outside the strike zone (outside the strike zone). This was calculated by dividing the number of pitches in the ball zone by the number of swinging strikes in the ball zone.

Note that owing to various conditions, such as player transfers within the team, injuries, and the number of NT sessions completed being less than 25, six participants had valid data available for the hitting performance analysis. The positions of the six batters used in the analysis were two catchers, one infielder, and three outfielders. In addition, all were right-handed throwers, two were right-handed hitters, and four were left-handed hitters. The six players were classified according to their hitting distance characteristics: two were short-distance types, three were medium-distance types, and one was long-distance type. The mean and standard deviation of the Slugging average of the six batters over the season was 0.351 ± 0.095 (Slugging average is the average of the total bases per at bat). The lowest and highest Slugging Average by Eastern League team in 2022 were 0.358 and 0.379, respectively.

2.4. Analysis

To examine the effect of MOT skill training and its transfer effect on hitting performance, we conducted paired t-tests on NT speed thresholds (n = 12) and hitting performance (n = 6) before and after the intervention. IBM SPSS Statistics software (version 28.0) was used for all statistical analyses. The significance level was set at <10% for a significant trend. Furthermore, the effect size of the Cohen's d index (*d*) was calculated using unbiased variance to estimate the population value.

3. Results

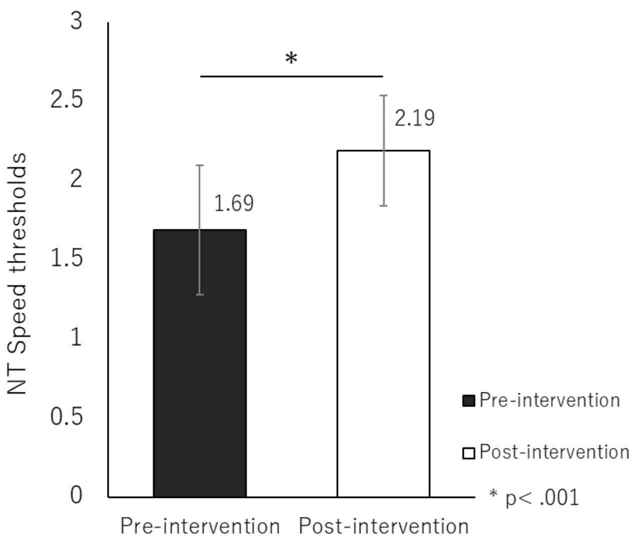

Figure 2. Changes in MOT skills before and after NT training.

3.1. Details on MOT skills training effectiveness and training session content

The NT scores showed a significant increase in performance (t (11) = -5.95, p < .001, d = -1.72) after training (M = 2.19, SD = 0.35) compared with before training (M = 1.69, SD = 0.41) (Figure 2).

The geometric mean thresholds for the 12 participants as a function of NT training sessions are expressed on a logarithmic scale (Figure 3). Note that as the number of completed NT sessions increased, the number of participants who completed the trials decreased; therefore, there was some variation in the data. The data were plotted using a simple logarithmic regression, and the R2 value was 0.43, indicating a moderate fit. Rapid progress in MOT skills is observed from the start of training to around 15 sessions, after which time the improvement in skills slows down. However, it can be concluded that a ceiling effect is still not seen even after the number of completed sessions exceeds 80.

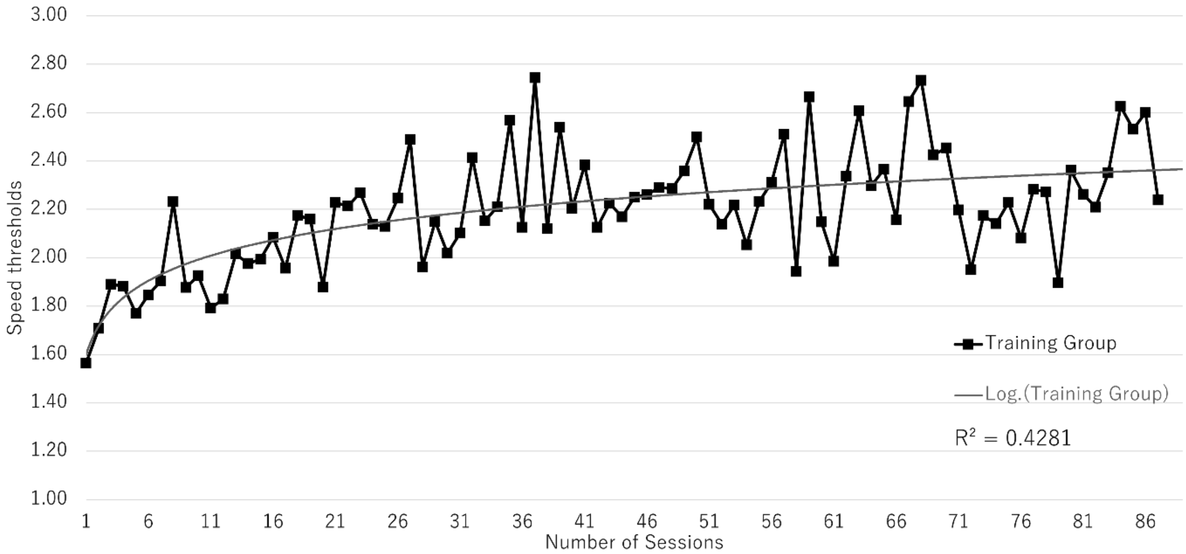

Figure 3. Geometric means of professional baseball players in relation to NT training sessions.

The details of the number of NT training sessions completed by the 12 participants, by training mode, and timing of training are summarized in Table 1. The average number of completed sessions was 44.67 (±25.26); in terms of mode differences, the CORE mode accounted for 88.97 % of all sessions, while the OVERLOAD mode accounted for 11.03 % of all sessions. The most common timing for NT training was after practice, accounting for 74.77 % of all sessions.

Table 1. *Timing, frequency, and mode of NT training.*

ID	***NT MODE***			***Time of NT training***							
	CORE(DUAL)	***OVERLOAD (DUAL)***	***Total Sessions***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***N/A***
1	*63(12)*	*8(4)*	*87*	*0*	*0*	*0*	*0*	*87*	*0*	*0*	*0*
2	*17(0)*	*1(0)*	*18*	*0*	*2*	*1*	*8*	*6*	*0*	*0*	*1*
3	*57(2)*	*8(2)*	*69*	*3*	*7*	*2*	*6*	*10*	*12*	*28*	*1*
4	*16(0)*	*1(0)*	*17*	*0*	*0*	*0*	*2*	*14*	*0*	*0*	*1*
5	*26(0)*	*2(0)*	*28*	*0*	*0*	*0*	*0*	*28*	*0*	*0*	*0*
6	*25(0)*	*1(0)*	*26*	*0*	*0*	*6*	*1*	*14*	*0*	*0*	*5*
7	*15(0)*	*1(0)*	*16*	*0*	*0*	*0*	*2*	*14*	*0*	*0*	*0*
8	*28(0)*	*2(0)*	*30*	*8*	*4*	*0*	*0*	*1*	*3*	*5*	*9*
9	*71(2)*	*7(2)*	*82*	*1*	*0*	*3*	*4*	*72*	*0*	*0*	*2*
10	*55(2)*	*7(2)*	*66*	*0*	*0*	*1*	*4*	*61*	*0*	*0*	*0*
11	*33(0)*	*3(0)*	*36*	*0*	*0*	*0*	*3*	*33*	*0*	*0*	*0*
12	*50(2)*	*6(2)*	*60*	*0*	*0*	*0*	*0*	*60*	*0*	*0*	*0*

Note: The number of NT training sessions completed by each of the 12 participants and the number of sessions completed in each mode are listed. The numbers in parentheses represent the number of DUAL task mode sessions *conducted. The average number of sessions completed by participants was 44.67 (±25.26). The mode of the NT task was CORE mode, which accounted for 88.97% of the total, and OVERLOAD mode, which accounted for 11.03% of the total. The most common time for NT training was after practice, accounting for 74.77% of the total. The timing of NT training is (1. after waking up, 2. before departure, 3. before practice, 4. during practice, 5. after practice, 6. after returning home, 7. before going to bed, N/A. Not Applicable).*

3.2. Effects of MOT skills training on hitting performance transitions

Effective data were obtained from six participants for whom hitting performance data were available before and after the start of NT training (Table 2). The mean and standard deviation of the number of plate appearance before and after NT training were pre-intervention, M = 82.17 ± 27.05 and post-intervention, M = 129.33 ± 9.60. The results showed no change in hit performance before and after NT training for the fastball-type pitches. However, there was a significant improvement trend in zone contact(t (5) = -2.28, $p < .10$, d = -0.93), zone-swing strike(t (5) = 2.48, $p < .10$, d = 1.01), and outside-swing strike(t (5) = 2.17, $p < .10$, d = 0.88) statuses after NT training for curveballs and other changeable pitches; the outside swing did not improve(t (5) = 0.85, p = 0.434, d = 0.35). The effect size of factors with significant differences was interpreted as large.

Table 2. *Changes in hitting stats before and after NT training.*

	Rate (%)	Pre-Intervention		Post-Intervention				95% CI		Cohen's
		M	***(SD)***	***M***	***(SD)***	***t* (5)**	***p***	***LL***	***UL***	***d***
Fastball types	Zone Contact[a]	0.863	(0.067)	0.836	(0.053)	0.97	.378	-0.05	0.10	0.39
	Zone-Swing Strike[b]	0.073	(0.052)	0.077	(0.029)	-0.25	.810	-0.05	0.04	-0.10
	Outside Swing[c]	0.294	(0.112)	0.277	(0.027)	0.40	.703	-0.09	0.13	0.17
	Outside-Swing Strike[d]	0.074	(0.070)	0.070	(0.024)	0.18	.861	-0.05	0.06	0.08
Other breaking ball types	Zone Contact[a]	0.635	(0.086)	0.711	(0.047)	-2.28	<.10	-0.16	0.01	-0.93
	Zone-Swing Strike[b]	0.170	(0.056)	0.127	(0.033)	2.48	<.10	0.00	0.09	1.01
	Outside Swing[c]	0.376	(0.118)	0.340	(0.049)	0.85	.434	-0.07	0.15	0.35
	Outside-Swing Strike[d]	0.196	(0.068)	0.144	(0.037)	2.17	<.10	-0.01	0.11	0.88

Note: N = 6: M = mean, SD =standard deviation, Cl = confidence interval; LL = lower limit; UL = upper limit. Fastball types include the Four-Seam Fastball and the Sinker etc. Other breaking ball types are breaking ball types include the Curveball and Slider etc. [a]The percentage of batted balls (including foul balls) that occurred when a batter swung. [b]Percentage of all pitches thrown in the strike zone that resulted in strikes when the batter swung at them. [c]The percentage of cases in which batters swung at pitches thrown outside the strike zone. Note that this *indicator does not mean swinging away. [d]The percentage of cases in which a batter swings at a pitch thrown outside the strike zone (outside the strike zone).*

4. Discussion

4.1. Effect of MOT skills training

Twelve participants who continued 3D-MOT training with NT tasks demonstrated a significant improvement in their MOT skills (*M* = 128%). Faubert and Sidebottom (2012) have found that highly skilled athletes exhibited higher average MOT skills than low-skilled athletes. However, they emphasize that MOT skills can be enhanced for athletes at all skill levels. Supporting this notion, Korobeynikova, Grushko, and Kasatkin (2015) have revealed that MOT skills are superior in soccer players at higher competition levels, in the order of professionals, amateurs, and novices. Furukado et al. (2019) have reported that 19 college baseball players' MOT skills improved after five weeks of training with NT tasks. These findings suggest that training MOT skills with NT tasks is effective for professional baseball players competing at a high level.

It is noteworthy that the average threshold of NT scores on a logarithmic scale with respect to MOT skill growth showed no ceiling effect, even after 80 sessions. Similar to the findings of Faubert and Sidebottom (2012), this study demonstrated a rapid increase in speed thresholds from the first 15 sessions to approximately 30 sessions, followed by gradual improvement in scores. Furukado et al. (2019) have reported mean NT scores (standard deviations) for amateur-level baseball players before (*M* = 1.35, *SD* = 0.37) and after the intervention (*M* = 1.92, *SD* = 0.51). Expressly, not only in soccer (Korobeynikova et al., 2015) but also in baseball, a correlation between higher competition levels and enhanced MOT skills was observed. Thus, it is significant that the MOT skill training intervention study on professional baseball players with a high level of athleticism illustrates a trend in MOT skill data over a five-month period.

As for the breakdown of NT training modes performed by the participants, the basic CORE mode accounted for nearly 90% of the training, and the remaining sessions involved the OVERLOAD mode. According to interviews conducted with the players by team coaches, some players reported the necessity of diversifying their MOT skills training beyond the CORE mode, as they tended to become disinterested in NT tasks when confined to a single mode. Therefore, more accurate MOT skill data can be collected by preplanning a training program with NT tasks within the team to eliminate variations in the mode in which NT tasks are performed.

In addition, to prevent overloading, it is crucial that modes that require substantial processing resources in the brain, such as DUAL tasks, are not implemented during the early stages of MOT skill training. These modes should be adjusted to the optimal difficulty level for the players. For athletes exhibiting considerable variation in NT scores, physiological indices measured during NT tasks can be employed for daily conditioning. For instance, Parsons et al. (2014) have discovered that 10 sessions of 3D-MOT task training induced quantitative changes in the resting neuroelectrical brain function. Similarly, emotion estimation systems based on EEG data analysis have emerged in recent years. If it becomes possible to quantify the degree of attention and concentration during NT training and provide feedback to players, it may contribute to enhancing their motivation for MOT skill training.

4.2. Transferability of MOT skills to hitting performance

Although the correlation between MOT skills and basketball performance indicators has been reported by both sides (Mangine et al., 2014; Phillips & Andre, 2023) and remains open for consideration, the potential for MOT skills to be transferred to sports performance discussions should be pursued. This is evidenced by Romeas et al. (2016), who state that training soccer players in MOT skills significantly improved passing and on-field decision-making accuracies before and after the intervention. The potential for transferring MOT skills training to baseball performance should also be examined (Furukado et al., 2019). To clarify this, we examined the transfer effect of MOT skill training on hitting performance. The results are intriguing in that no transfer effect of MOT skill training was found in the fastball condition but was found in the breaking ball condition.

Generally, the time for a pitch to reach the catcher's mitt is approximately 0.4–0.5 seconds for fastballs and 0.5–0.6 seconds for breaking pitches. When the pitcher begins the pitching motion, the batter initiates the preliminary actions related to the swinging motion by employing a strategy that minimizes the time required for the hitting action. Additionally, it takes about 0.15 seconds from the start of the swing to the impact on the ball; thus, the swing must commence approximately 0.3 seconds after the pitch is thrown to make impact in time. Furthermore, it takes approximately 0.15 seconds to incorporate the information on the pitch type into the swinging motion, resulting in a brief time window to judge the pitch type (approximately 0.15 seconds).

Kato and Fukuda (2002) have reported that, during the pitch release phase, the visual search strategy captures the pitcher's entire body from the release point by placing the visual pivot around the pitcher's elbow, utilizing a peripheral vision system skilled at grasping fast-moving objects rather than central vision. Expressly, the batter uses this peripheral vision system to distinguish between pitches. The NT task was designed to place the visual pivot on a small dot fixed at the center of the monitor and track the movement of multiple objects through information processing by the peripheral vision system. If the input of visual information to the brain can be efficiently processed, more energy can be allocated to higher brain and auditory functions. Thus, the observed transfer effect may be attributed to the commonality between baseball hitting performance and information processing by the peripheral vision system, which is necessary for 3D-MOT tasks. Specifically, it can be concluded that information processing by the peripheral vision system was transferred to a decrease in the zone-swing strike rate, improvement in the zone contact rate, and decrease in the outside-swing strike rate, all of which are related to the judgment of pitch type. If a quantitative evaluation of the peripheral vision system becomes possible in sports vision research, we can investigate its correlation with NT task scores to gain further insights into the transfer effect of MOT skill training on performance. Further study is needed from here, but since fastballs take less time to reach the catcher's mitt than change balls, the body does not respond in time during the time reflection in the batting action to the impact phase, and this may be attributed to swing skill. It is also possible that hitters finally became accustomed to the ball trajectory of the breaking ball in the second half of the season, unlike the straight pitches they have been accustomed to since the first half of the season, and improved their ability to respond.

Limitations of this study include the inability to collect and evaluate data on MOT skills, including those of the control group. The participants who performed the NT training in this study usually practiced jointly or individually within their teams, and it is premature to conclude that the transfer effect to hitting performance was purely a result of NT training. In addition, it is necessary to proceed with the study by constructing an elaborate experimental design, such as isolating the batting motion into phases and determining the phase of the hitting motion to which the MOT skill training effect transfers. Future research should also investigate the transfer effect on other statistical measures, such as defense and base running, to understand the effects of MOT skills on baseball performance.

5. Conclusions

This study demonstrated the transfer effects of perceptual-cognitive skills training in a laboratory setting, outside of a sports context, on hitting performance in baseball. In addition, the 3D-MOT training, which processed complex and dynamic visual scenes and proved effective for professional baseball players, led to improvements in the zone contact rate, zone-swing strike rate, and outside-swing outside rate. Information processing by the peripheral vision system required during the MOT task was also common during hitting, and it was assumed that this was the reason for the transfer effect on hitting performance. However, it should be noted that the insufficient sample size, including the control group, was an obvious limitation of this study, and further data accumulation is required.

Author Contributions

Conceptualization, R.F.; methodology, R.F., H.I., Y.S.; software, H.I., Y.S.; validation, R.F.; formal analysis, R.F.; investigation, T.I., K.M., D.E.; resources, R.F., T.I., K.M., D.E.; data curation, R.F.; writing—original draft preparation, R.F.; writing—review and editing, R.F., H.I., Y.S.; visualization, R.F.; supervision, H.I.; project administration, H.I., T.I.; funding acquisition, H.I., Y.S.; All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

References

Adair, R. K. (1995). The physics of baseball. *Physics Today, 48*(5), 26-31.

Faubert, J., & Sidebottom, L. (2012). Perceptual-cognitive training of athletes. *Journal of Clinical Sport Psychology, 6*(1), 85-102. https://doi.org/10.1123/jcsp.6.1.85

Furukado, R., Akiyama, D., Sakuma, T., Shinriki, R., Hagiwara, G., & Isogai, H. (2019). Training Effect of Multiple Object Tracking Skills: An Investigation on Visual Search Strategies. *The Japanese Journal of Ergonomics*, *55*(2), 33-39. https://doi.org/10.5100/jje.55.33

Garland, D. J., & Barry, J. R. (1990). Sport expertise: The cognitive advantage. *Perceptual and Motor Skills, 70*(3_suppl), 1299-1314. https://doi.org/10.2466/pms.1990.70.3c.129

Goodale, M. A., & Milner, A. D. (1992). *Separate visual pathways for perception and action. Trends in neurosciences, 15*(1), 20-25. https://doi.org/10.1016/0166-2236(92)90344-8

Kato, T., & Fukuda, T. (2002). Visual Search Strategies of baseball batters during the preparatory phase of batting. *The Japanese Journal of Ergonomics, 38*(6), 333-340. https://doi.org/10.5100/jje.38.333

Korobeynikova, E.Y., Grushko, A.I., & Kasatkin, V. (2015, May). Multiple target tracking in football: visual attention at different levels of football experience. *The 8th World Congress on Science and Football, Denmark.* https://doi.org/10.13140/RG.2.1.3623.0562

Levitt, H. C. C. H. (1971). Transformed up‐down methods in psychoacoustics. *The Journal of the Acoustical society of America, 49*(2B), 467-477. https://doi.org/10.1121/1.1912375

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. A., ... & Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences, 103*(33), 12523-12528. https://doi.org/10.1073/pnas.0605194103

Mangine, G. T., Hoffman, J. R., Wells, A. J., Gonzalez, A. M., Rogowski, J. P., Townsend, J. R., ... & Stout, J. R. (2014). *Visual tracking speed is related to basketball-specific measures of performance in NBA players. The Journal of Strength & Conditioning Research, 28*(9), 2406-2414. https://doi.org/10.1519/JSC.0000000000000550

Meyerhoff, H. S., Papenmeier, F., & Huff, M. (2017). Studying visual attention using the multiple object tracking paradigm: A tutorial review. *Attention, Perception, & Psychophysics, 79*, 1255-1274. https://doi.org/10.3758/s13414-017-1338-1

Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Bérubé, S., ... & Faubert, J. (2014). Enhancing cognitive function using perceptual-cognitive training. *Clinical EEG and neuroscience, 47*(1), 37-47. https://doi.org/10.1177/15500594145637

Phillips, J., & Andre, T. (2023). Visual tracking speed threshold in NCAA Division I women's soccer predicting match performance: A preliminary study. *Scientific Journal of Sport and Performance, 2*(1), 94-104. https://doi.org/10.55860/REVS9403

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial vision, 3*(3), 179-197. https://doi.org/10.1163/156856888X00122

Romeas, T., Guldner, A., & Faubert, J. (2016). *3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. Psychology of Sport and Exercise, 22*, 1-9. https://doi.org/10.1016/j.psychsport.2015.06.002

Tullo, D., Faubert, J., & Bertone, A. (2018). The characterization of attention resource capacity and its relationship with fluid reasoning intelligence: A multiple object tracking study. *Intelligence, 69*, 158-168. https://doi.org/10.1016/j.intell.2018.06.001

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Article

Development of Video Switching System in Sport Fields

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Abstract
In Japan, the Sport Basic Plan was formulated in 2012, which mentions not only the development of highly qualified sports instructors but also new perspectives such as the provision of programs in which everyone can enjoy the value of sports together. Against this background, trials of new technologies utilizing the latest ICT equipment such as sensor devices are being made. However, in college sports, where financial resources are often limited, shooting with hand-held video cameras is the most common method, which may cause the manager to overlook important scenes of play depending on his or her skill level. This problem affects not only competitors but also spectators. To solve this problem, we develop a system for capturing video images of the entire field with multiple fixed video cameras so that the system can automatically switch from one to another video of the most appropriate camera for the respective scenes of play. The results of the demonstration experiments in basketball and futsal showed that the switching video of the proposed technology can be utilized for tactical analysis in sports.

Keywords: Sports; Multiple cameras; Player tracking; Video switching; Time-series difference.

1. Introduction

In Japan, the Sport Basic Plan (Ministry of Education, Culture, Sports, Science and Technology, 2023a) was formulated in 2012, which outlines the key principles of sport promotion for the 10-year period and the policies to be taken over five years. This plan aims at sound development of youth, creation of economic vitality, and improvement in the international status through the promotion of sports. In addition, the third phase of the plan was formulated in 2022, which mentions not only the development of highly qualified sports instructors but also new perspectives such as the provision of programs that allow everyone to enjoy the value of sports together (Ministry of Education, Culture, Sports, Science and Technology, 2023b).

Against this background, trials of new technologies have been made to aim at improving the level of competition as well as entertaining property of sports by utilizing ICT equipment such as sensor devices and video cameras (Tanaka et al., 2020; Haraguchi et al., 2011). However, in college sports, of which financial resources are often limited, capturing videos using a video camera is the most common method. Specifically, a team manager holds a video camera in his or her hand, follows the players and shoot them while adjusting the angle of view at the same time. After

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practices or games, the head coach and coaches check the video and analyze players' performance. However, when a game develops rapidly, the manager may be unable to adjust the angle of view in time and miss the ball or players. The manager may even be overlooking important scenes of play depending on the skill level. This problem is not limited only to the teams competing but also affects the spectators similarly. In order to capture important scenes of play in a game, it is necessary to keep holding the camera in position throughout the game and follow the play. This imposes a burden on the cameraman, who can't enjoy the game.

In this study, we develop a system that captures videos of the entire field with multiple fixed video cameras and automatically switches from one to another video of the appropriate camera according to the respective playing scene (hereinafter referred to as "switching"). By developing this system, the cameraman does not have to hold a video camera in his or her hand and follow the playing scene but can always capture the video provided by the system that always switches to the most appropriate camera. This will allow the team managers and spectators to always capture the video of the game that captures the playing scene without fail, contributing to the advancement of play analysis for sports teams and the improvement in the entertainment value of the captured video for spectators.

2. Devising Video Switching Algorithms

In this study, we devise a technology that allows automatic switching to the video of the appropriate camera without the need for manual shooting. In specific, fixed multiple video cameras are installed to capture video of a game that covers the entire field. Then, a video is generated by automatically switching the camera to be used based on the position of the ball in the angle of view, the number of people on the court, and the position of the players (hereinafter referred to as "switching video").

The processing flow of the proposed system is shown in Fig. 1. This system consists of a function for constructing ball and person detection models and a function for generating switching video.

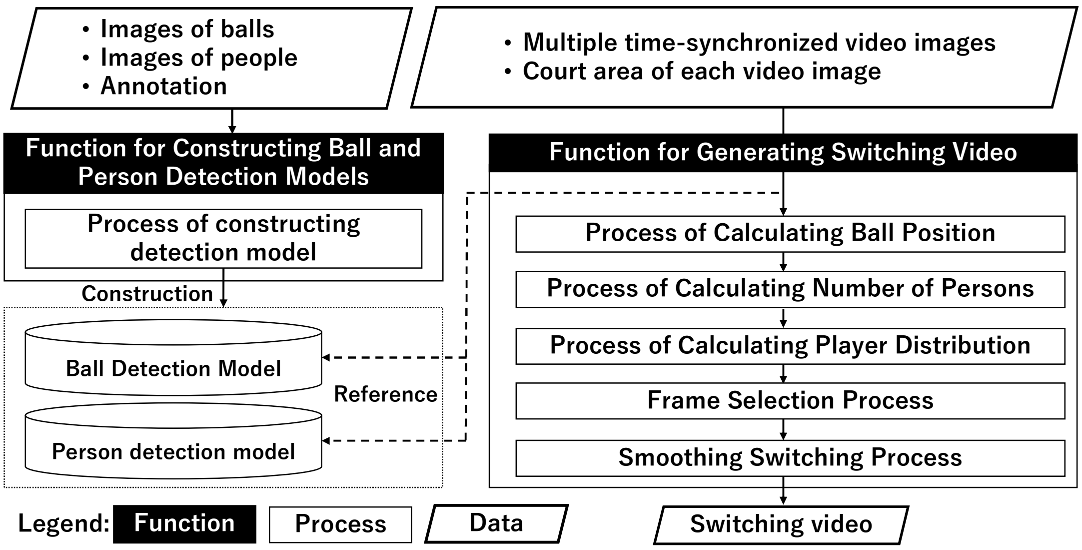

Fig. 1. Process flow

2.1. Function for Constructing Ball and Person Detection Models

This function is used to create a set of images in which a ball or a person is captured, as well as the coordinate values of a rectangular region on the image (hereinafter referred to as "annotation"). These are then learned by YOLOv4 (Bochkovskiy et al., 2021), an object detection and recognition algorithm, to construct a ball detection model and a person detection model.

2.2. Function for Generating Switching Video

Firstly, this function is used to detect the ball and players from the same frame of the video captured by multiple time-synchronized video cameras. Second, it is used to calculate the positions of the ball and persons and the number of people, then compare them to select the frame in which the play is taking place at the nearest point to the center of the angle of view. Then, the appropriate camera number is chosen from the selected frame. Finally, each frame is combined to generate a switching video.

2.3. Process of Calculating Ball Position

This process calculates the distance between the ball and the center of the X coordinate of the angle of view in each frame. First, the ball is detected from the frame using the ball detection model constructed by function for constructing the ball and person detection models. Second, as shown in Fig. 2, the distance between the center of the X-coordinate of the detection frame of the detected ball and the center of the X-coordinate of the angle of view is calculated from the number of pixels. Finally, by repeating this for the number of cameras, the distance between the ball and the center of the angle of view in each frame is extracted.

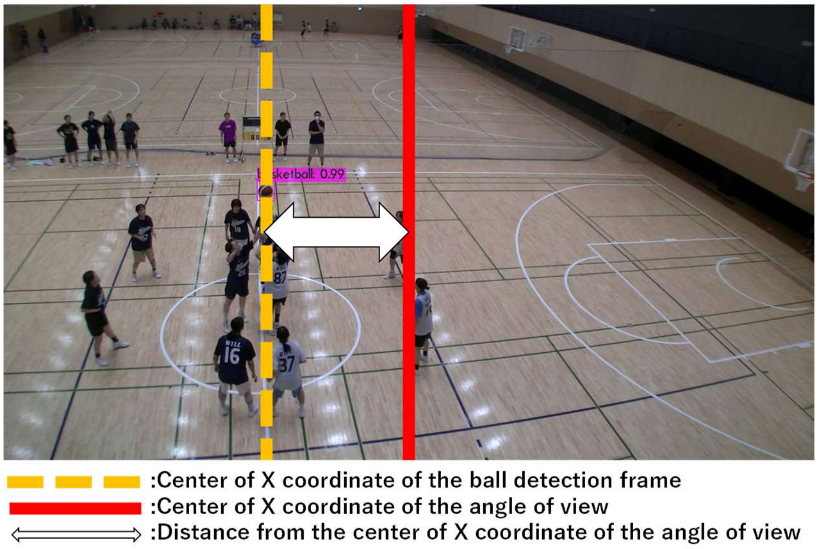

Fig. 2. Process of calculating ball position for basketball

2.4. Process of Calculating Number of Persons

This process calculates the number of persons in the court in each frame. First, the area of the court in each video image is manually input. Second, all persons in the image frames are detected using the person detection model. Then, concerning all the persons detected, the bottom of the center of the detection frame of each detected person is considered positional information of the person. Finally, only those persons who are located within the input area of the court are calculated. This is repeated for the number of cameras to obtain the number of persons in each frame.

2.5. Process of Calculating Player Distribution

In this process, distribution of players is obtained by calculating the average of the distances from the position of the players within the angle of view to the center of the angle of view. First, just as the process of calculating the ball position, the distance between the person within each frame in the angle of view and the center of X coordinate of the angle of view is calculated. Then, this calculation is repeated for the number of players, and the average is calculated to obtain the average distance from all of the players in the angle of view to the center of angle of view. This makes it possible to select the frame in which players are concentrated at the center of the angle of view in case that there are multiple frames with the same number of players.

2.6. Frame Selection Process

This is a process of comparing the outputs from the functions of calculating ball position, the number of persons, and player distribution, then selecting and combining the frame images captured by the appropriate camera to create the switching video. Selection is made in the following order of priority:

1. The camera with the ball being closest to the center,
2. The camera with the largest number of players in the angle of view,
3. The camera with player distribution being closest to the center.

2.7. Smoothing Switching Process

In the frame selection process, the switching video is created by comparing the ball, player positions, and number of players for each frame. Therefore, it is considered that the wrong selection of frames due to wrong detection or failure of detection results in inappropriate camera numbers being scattered throughout the frame, causing the video to flicker as one video switches to another at high speed. In order to suppress this flickering phenomenon, switching is smoothed by decision by majority at a regular frame interval (hereafter referred to as "smoothing interval") in this process.

2.8. Trials in Basketball

In this experiment, we verify the switching accuracy of the proposed method by comparing the switching video generated by the proposed method and the existing method. Additionally, we interview the instructors of Kansai University Women's Basketball Club to evaluate the usefulness of the system from the instructor's point of view.

2.8.1 Experiment Outline

In this experiment, first, a switching video is manually created to serve as correct-answer data using video taken with a video camera from the position shown in Fig. 3 for approximately 2 minutes from the beginning of the game between the two halves of a team. For a video camera, A SONY / FDR-AX40 capable of shooting at 4K quality at 60 fps was used. Second, the proposed method and the existing method (Iguchi et al., 2002) are applied to the video of the same game above to generate switching video. Finally, the correct-answer data is compared with the switching videos created with the proposed and the existing methods respectively to evaluate the precision, recall, and F-measure.

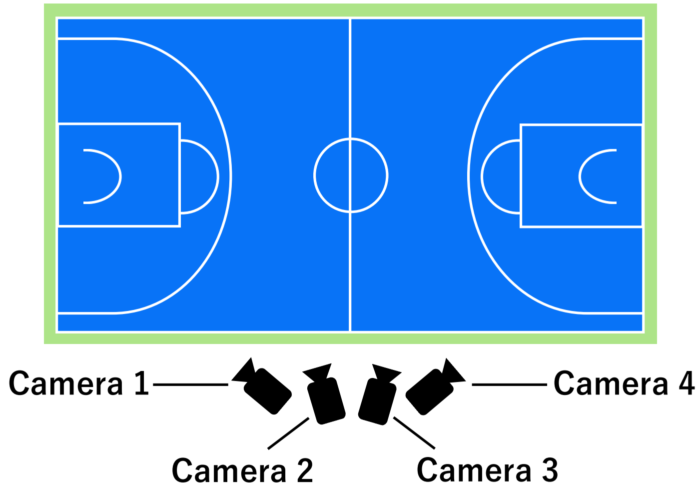

Fig. 3. Position of installing video cameras for basketball

2.8.2 Experimental Results and Discussion

The evaluation results of the proposed and existing methods shown in Table 1, and examples of switching video selection shown in Fig. 4. Table 1 shows that from the existing method, precision is 0.41, recall is 0.45, and F-measure is 0.43, indicating that it is difficult to select appropriate frames. On the other hand, from the proposed method, precision is 0.72, recall is 0.71, and F-measure is 0.71, indicating that appropriate frames can be adopted compared with the existing method. Although the precision was 0.72 and there were some cases that switching failed in some frames, it was found that the smoothing approach allowed the flickering phenomenon to be lowered to just one time. The visualization results shown in Fig. 4 also indicate that this method allowed appropriate selection of a camera.

In order to confirm the usefulness of the switching video generated by the proposed method, we interviewed the head coach and manager of the women's team of Kansai University Basketball Club. As a result, they answered that the proposed method is useful for tactical analysis because it enables them to grasp the positions of players involved in pass plays.

Table 1. Evaluation results of proposed and existing methods

methods	Switching	Flickering phenomenon	Evaluation (Average of 4 cameras)		
			Precision	Recall	F-measure
Manually	20	0	—	—	—
Existing	387	203	0.41	0.45	0.43
Proposed	25	1	0.72	0.71	0.71

Fig. 4. Example of switching video selection for basketball

Based on the above results, the switching video of the proposed method is considered useful in the field of sports owing to its applicability to tactical analysis as well as highly entertaining property.

3. Proposal of Video Switching System

In this study, we develop a video switching system with the aim of social implementation of the video switching algorithm we devised and contribution to the promotion of college sports. The system inputs video from fixed video cameras shooting at multiple locations, and outputs switching video that switches to the appropriate camera according to the playing scene through the switching video playback function, the function for narrowing down generation range, the function for specifying analysis area, and the function of automatically generating switching video. The number and positions of the video cameras can be freely set.

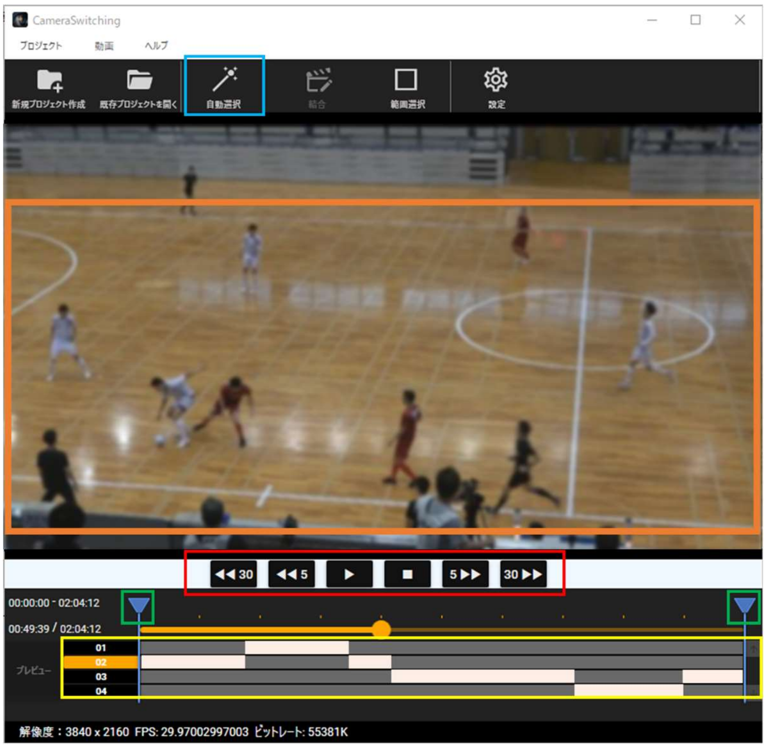

Fig. 5. UI of video switching system

3.1. Switching Video Playback Function

As shown in the red frame in Fig. 5, this function allows playback while switching between the videos input from multiple video cameras. It allows controlling playback, stopping, fast forwarding, and reversing of the video. The playback position can be selected arbitrarily using the seek bar. It also allows switching to any video by selecting it from the yellow frame in Fig. 5.

3.2. Function for Narrowing Down Generation Range

Video captured by a video camera may include pre- and post-game scenes or video taken while the video camera is being prepared for installation. In addition, it is not necessary to analyze all frames of a video, while it is also possible to generate switching video for only some of the playing scenes. Accordingly, as shown in the green frame in Fig. 5, this function can be used to narrow down the range of automatic generation of switching video using the seek bar.

3.3. Function for Specifying Analysis Area

Since there are referees, spectators, etc. near the field, there is a risk of their appearance in the captured video, which may cause failure in appropriate camera selection due to their movements. Therefore, as shown in the orange frame in Fig. 5, this function is used to specify the analysis area on the video to achieve analysis targeting only the players on the field.

3.4. Function of Automatically Generating Switching Video

As shown in the blue frame in Fig. 5, only by clicking the button, this function can be used to automatically select the appropriate camera and generate the switching video based on the knowledge of the video switching algorithm we have devised. Emphasizing comfortable operation feel to use as a client system, the following two improvements are added to the video switching algorithm of this system.

- Improved frame selection process

In the frame selection process, the frame to be switched is selected based on the person or ball detected by deep learning. However, the processing cost of deep learning is so high that if it is incorporated into client software, it may cause an enormous amount of waiting time for analysis results, which has a risk of significantly impairing the comfort of the system. Consequently, emphasizing light operation, the camera with the highest number of pixels in the time-series difference is adopted with priority in the frame selection process.

- Analysis Frequency Setup

With video switching algorithms, analysis is performed for all frames. However, there is a problem that the selected frame changes continuously for each frame, causing flickering phenomenon. In fact, flickering phenomenon is observed in a trial experiment in basketball. Therefore, setting the analysis frequency as a parameter, the frame selection process is performed for each analysis frequency rather than for all frames. This suppresses the flickering phenomenon. It also contributes to reduction of the analysis time as the number of frames to be analyzed can be narrowed down.

4. Demonstration Experiment

In this experiment, the usefulness of the system is evaluated by applying the video switching system to the video of a futsal game and checking the analysis time and switching accuracy.

4.1. Experimental Plan

Two experiments are conducted as follows: "Experiment 1: experiment on the analysis Frequency" and "Experiment 2: experiment on the smoothing interval". Experiment 1 is performed to check the analysis time that varies with the analysis frequency and clarify the optimal analysis frequency. Experiment 2 is performed to check the switching accuracy that varies with the smoothing interval and clarify the optimal smoothing interval.

4.2. Experimental Data

In this experiment, an actual futsal game is shot from the camera position shown in Fig. 6. Video cameras to be used are SONY / FDR-AX40 (4K quality, 30 fps) and JVC / Sports Coaching Cam (Full HD quality, 60 fps). The video of 15 minutes from the kickoff is extracted as experimental data.

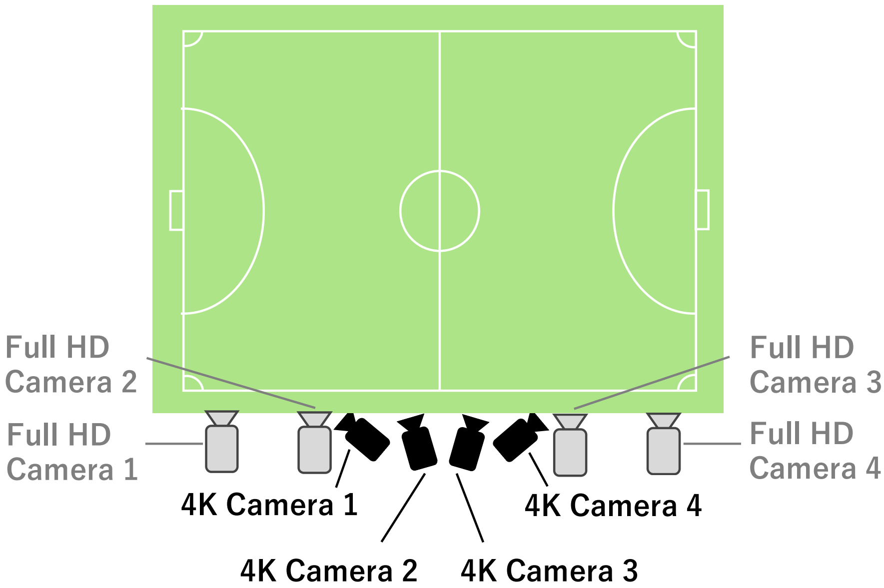

Fig. 6. Position of installing video cameras for futsal

4.3. Experiment 1: Experiment on Analysis Frequency

In Experiment 1, this system is applied to the videos shot by two cameras, one with 4K picture quality and the other with Full HD picture quality, to check the analysis time depending on the analysis frequency.

4.3.1 Experimental conditions

The higher the analysis frequency is set, the lighter the operation feeling can be. On the contrary, there is a possibility that the video switching cannot respond to the play transition and the system may continue to select an inappropriate camera. Thus, in this experiment, the analysis frequency is set to 100 ms, 200 ms, 500 ms, 1,000 ms, 1,500 ms, 2,000 ms, and 3,000 ms. The target analysis time is set to 8 hours, assuming that the user can confirm the results of one game shot during the daytime in one night.

4.3.2 Experimental results

The results of this experiment shown in Table 2. Table 2 indicates that the analysis time for the 4K camera is 8 times longer than that for the Full HD camera at 100 ms. However, the processing time for the 4K camera at 100 ms was longer than the target value despite a 15-minute video, while at 1,000 ms or less, the processing time was less than one hour, which is the same level as that for the Full HD camera.

Then, based on the results in Table 2, we summarized the analysis time assumed for the whole video of one futsal game (1 hour and 20 minutes) with a 4K camera in Table 3. Table 3 shows that analysis frequencies of 500 ms or less are assumed to take longer than the target value. On the other hand, at 1,000 ms, the analysis time is approximately 4 hours and 30 minutes, which is far below the target value.

Table 2. Analysis time for
4K and Full HD camera

Frequency	4K	Full HD
100ms	8h38m26s	0h56m24s
200ms	4h22m38s	0h27m38s
500ms	1h44m50s	0h10m38s
1,000ms	0h52m12s	0h05m01s
1,500ms	0h33m55s	0h03m20s
2,000ms	0h25m18s	0h02m30s
3,000ms	0h16m36s	0h01m34s

Table 3. Analysis time assumed
for whole video of futsal game

Frequency	4K
100ms	approximately 45 hours
200ms	approximately 23 hours
500ms	approximately 9 hours
1,000ms	approximately 4 hours and 30 minutes
1,500ms	approximately 3 hours
2,000ms	approximately 2 hours and 15 minutes
3,000ms	approximately 1 hours and 30 minutes

From the above, it is clear that 1,000 ms is the optimum for the analysis interval of this system.

4.4. Experiment 2: Experiment on the Smoothing Interval

In this experiment, the switching accuracy is confirmed by comparing the manually created switching video as the correct data with the analysis results of the system. Regarding the switching accuracy, we check the coincidence ratio between the cases when selection of the adjacent camera is not allowed and when it is allowed. This is because it is sometimes difficult to determine the optimal camera between two cameras with partially overlapping video recording areas even with visual check, and consequently two patterns are evaluated in consideration of these cases.

4.4.1 Experimental conditions

In this experiment, a camera with Full HD picture quality, which is commonly used, is applied to the system. At this time, the analysis interval is set to 1,000 ms, which was made clear in Experiment 1. Fig. 7 shows the videos from each camera applied to the proposed system and the analysis area specified in the system.

Fig. 7. Video images from each camera and its analysis area

In this experiment, the smoothing intervals are set to 0 (no smoothing), 2, 4, 6, 8, and 10. The larger the smoothing interval is, the more local wrong determination can be decreased; however, it may not be able to deal with rapid transitions in the players' play.

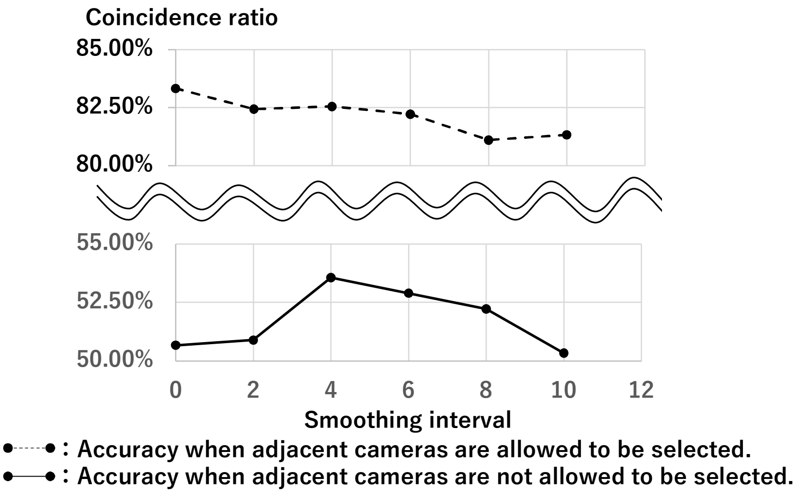

Fig. 8. Accuracies with and without allowing selection of adjacent cameras

4.4.2 Experimental results

The accuracies with and without allowing the selection of adjacent cameras are shown in Fig. 8. Fig. 8 clearly indicates the following items.

- Improved accuracy by way of a smoothing process

In Fig. 8, the coincidence ratio without smoothing is 50.67%. When a smoothing interval is set up, the coincidence ratio converged at the smoothing interval 4 and increased up to 53.56%. This clearly shows the usefulness of the switching smoothing process.

- Successful generation of appropriate switching video

In Fig. 8, the accuracy has improved most at the smoothing interval. However, the coincidence ratio is 53.56%, which means that almost half have selected the wrong camera. However, In Fig. 8, the coincidence ratio is 82.56 at the smoothing interval 4, suggesting that the majority have selected the adjacent camera. The video images also indicated that players' play was captured in both cameras of the correct answer and the adjacent one, which we confirmed were switching video without an uncomfortable feeling.
From the above, it was made clear that the proposed system is capable of generating appropriate switching video.

- Wrong determination due to detection of non-athlete movement

Checking the switching video that had wrong determination except about the adjacent camera, cases of wrong determination were observed here and there due to the detection of movements other than those of players.

First, a case of detecting the movement of a spectator was observed. As shown in Fig. 9, since this experiment was conducted by shooting video from behind the spectators' seats, when a spectator stood up and moved, an occlusion occurred between the court that was the analysis area and the spectator. Since the spectator appeared larger than the player in the distance, the camera in front of the spectator was selected instead of the camera that should have been selected.

Fig. 9. Example of detecting spectator movement (Camera 1)

In some cases, the motions of referees and reserve players were detected. As shown in Fig. 10, the referee and reserve players were moving around the court, generating occlusions with the court, which were wrongly detected as a players' movements.

Fig. 10. Example of detecting movement of referees and reserve players (Camera 2)

As described above, there was a tendency for switching accuracy to decline due to the movements of those other than players, captured within the court. This problem can be solved by the following measure. First, for the function for specifying the analysis area of the system, specification with a rectangle was adopted giving priority to ease of manual specification. However, as shown in the orange frame in Fig. 5, in specifying some area with a rectangle, areas other than the court are also contained within the specified area, and the movements of spectators, referees on the sides of the court, and reserve players become factors that reduce the accuracy. Therefore, as shown in Fig. 11, it is possible to suppress movements other than those of players from entering the analysis area, by setting up the vertices of the area arbitrarily rather than using a rectangle and specifying the court area precisely.

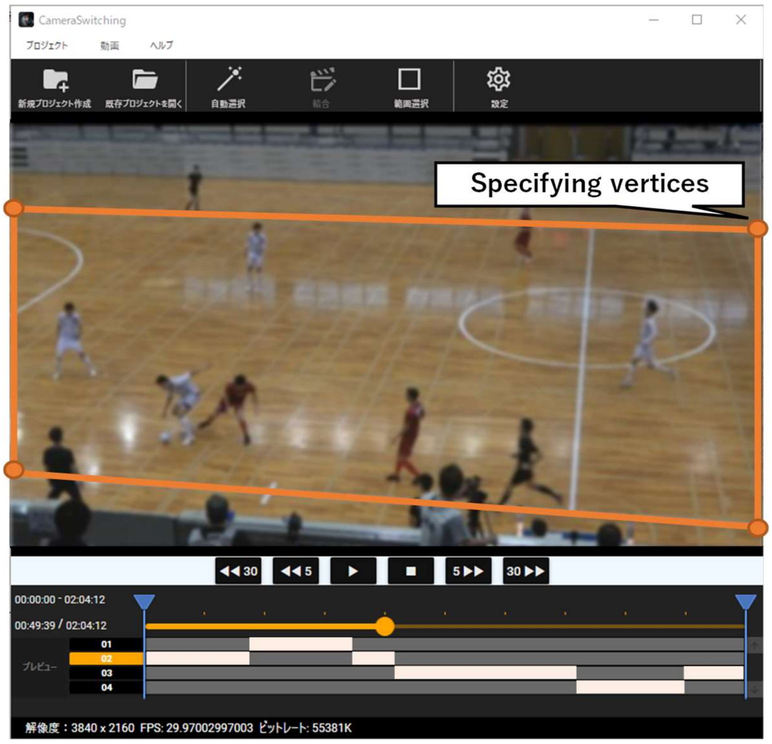

Fig. 11. Function for specifying analysis area by specifying vertices

In addition, the pixels of the time-series difference are labeled. Concerning the difference that spread out to the outside of the court, it is considered the difference caused by those other than players and excluded in the frame selection process. By doing so, we believe this problem can be addressed.

- Applicability to Other Sports

From the above results, the usefulness of this system was confirmed in basketball and futsal. Since this system determines the camera to be selected based on the time-series difference caused by the movements of the players, it is considered applicable to outdoor field sports such as soccer as well. On the other hand, its application to sports where players move simultaneously across the entire court, like volleyball, is considered difficult. However, the applicability of these must be quantitatively verified in the future.

The above results indicate that the system is capable of creating switching video by calculating the time-series difference of respective frames from the video images captured by multiple video cameras. It is clear that this enables creation of the same level of switching video as capturing by manual tracking at a low cost.

5. Conclusions

In this study, we proposed a technology of generating switching video for college sports by automatically selecting an appropriate camera from among the multiple video cameras installed based on the positions of the ball or players. Through experiments and interviews, it was found that the switching video of the proposed technology can be utilized for tactical analysis.

In addition, as a social implementation of the findings of this research and development, we developed a video switching system, establishing an environment in which anyone can easily capture switching video simply by setting up cameras in the field. In the future, we aim at contributing to the development of the sports field by improving the functions of this system and promoting its widespread use. This paper has been translated and revised based on the technical description (Umehara et al., 2023) published in the Image Lab.

References

Bochkovskiy, A., Wang, Y. and Liao, M. (2021). YOLOv4: Optimal Speed and Accuracy of Object Detection, arXiv preprint arXiv:2103.13343.

Haraguchi, T., Taki, T. and Hasegawa, J. (2011). “Development of Automated Tracking System with Active Cameras for Figure Skating”, *IEEJ Transactions on Industry Applications*, IEEJ, *131*(4), 565-571.

Iguchi, Y., Doi, M., Manabe, Y. and Chihara, K. (2002). “Automatic Multi-Camera Control and Switching for Sports Game Broadcasting Based on Real-Time Video Analysis”, *Journal of the Institute of Image Information and Television Engineers*, ITE, *56*(2), 271-279.

Ministry of Education, Culture, Sports, Science and Technology. (2023a). the Sport Basic Plan, https://www.mext.go.jp/component/a_menu/sports/detail/__icsFiles/afieldfile/2012/04/02/1319359_3_1.pdf.

Ministry of Education, Culture, Sports, Science and Technology. (2023b). 3rd Sport Basic Plan (outline), https://www.mext.go.jp/sports/content/000021299_20220316_1.pdf.

Tanaka, C., Yamamoto, Y., Jiang, W., Tanaka, S., Nakamura, K. and Nakajima, S. (2020). “Research for Pass Matchup Analysis Considering Movement Records in American Football”, *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics*, SOFT, *32*(1), 580-589.

Umehara, Y., Jiang, W., Nishita, Y., Yamamoto, Y., Naruo, T., Tanaka, S. and Yokomichi, A. (2023). “Development of Video Switching System for Sports”, *Image Laboratory*, Japan Industrial Publishing Co., Ltd, *34*(8), 23-28.

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Article

Visualization of Motion Image by Humanoid Input Device for Shooting Motion in Basketball and Its Effectiveness

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Abstract
The use of imagery is effective for the acquisition of sports movements. However, the details of recalled images have not yet been clarified. Therefore, the purpose of this study was to visualize the image of a basketball shooting motion using a humanoid input device. We also aimed to clarify the effects of such visualizations on the formation of the players' movement images and the understanding of their movement skills. Six elite female athletes belonging to a professional team and six high-school female athletes who had participated in national tournaments were selected as participants, and motion images were created using a humanoid input device. The results of the analysis indicated that the detailed reproducibility of the motion images and the relationship between the individual movements and the whole movement differed according to the proficiency level of the shooting movement. In addition, it was suggested that in the acquisition of the shooting motion, the promotion of metacognitive activities for one's own motion enhances the analytical and individual sensory understanding of the motion, as well as the formation of an image that relates the whole motion.

Keywords: Movement Imagery, Reflection, Metacognitive Activities.

1. Introduction

The acquisition of sports movement skills is called "sensory-motor learning," which involves a cooperative relationship between the sensory and motor systems and follows a process of mastery from the trial-and-error stage, through the regulation stage, to the automatic stage (Yamada et al., 2021). Kitamura (2011) highlighted the importance of athletes understanding the sequence of movements and expressing it as an overall series of natural movements after connecting their understanding with their own senses in the acquisition of sports movements. The key to this is imagery ability. Imagery in sports is defined as the creation or reproduction of experiences generated from memory information containing quasi-sensory, quasi-perceptual, and quasi-emotional characteristics under the control of consciousness (Annett, 1995; Morris et al., 2005). Furthermore, because imagery ability reflects an individual's ability to form, maintain, and transform images, such as vividness and ease (Williams and Cumming, 2011), it can be expected that enhancing an individual's imagery ability will have a positive effect on learning using imagery. In addition to movement acquisition, imagery is used in various situations in sports learning, such as tactical understanding, motivation, and psychological conditioning, and its effectiveness has also been studied. Furthermore, many studies on training using such imagery have been reported, and many have shown that the effectiveness of such imagery can be expected to improve when training methods are devised. For example, Cooley et al. (2013) reported an approach based on the physical, environment, task, timing, learning, emotion, perspective (PETTLEP) model

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(Holmes and Collins, 2001). The PETTLEP model is an imagery training method that takes into account seven factors that should be considered when recalling motor imagery. However, insufficient research has been conducted regarding the effective use of the PETTLEP model (Munroe-Chandler et al., 2012; Dickstein et al., 2004). In addition, images have both a descriptive aspect (the sensory part of the object) and an explanatory aspect (the interpretation or understood meaning of the object) (Miyazaki, 1980). Because images are internal processes, they are difficult to visualize, and their inner reality is difficult to grasp (McAvinue and Robertson, 2008). Therefore, it has been pointed out that the discrepancy between the image that athletes have of their own movements and the actual movements is problematic for them and that the effectiveness of image training is affected by how well or poorly they are doing (Hasegawa and Hoshino, 2001). Thus, because it is difficult to grasp the details of the movement images that players draw, we believe that the visualization of the images is important in the investigation of training using imagery.

Therefore, in this study, we attempted to visualize the motion images drawn by players by reproducing their motion images on a computer using a humanoid input device. The purpose was to examine the influence of such image visualization on players' understanding and acquisition of movement skills.

Because the purpose of this study was to analyze the details of players' experiences in recalling images, we judged that a qualitative research method was appropriate (Kitamura et al., 2005) and adopted it as the methodology.

2. Methods

2.1. Participants

The 12 participants in this study were six high school female basketball players who had participated in a national tournament and six professional female basketball players who belonged to a professional women's basketball team. The 12 participants were classified according to their level of proficiency: 3 high school students as intermediate players (participants A,B,C), 3 high school students as advanced players (participants D,E,F), and 6 professional players as proficient players (participants G to L).

2.2. Procedure

The survey was conducted from October 20XX to January of the following year. Before the survey, the operation of the humanoid input device used in this study was explained. After that, all participants were asked to use the device freely. After it was confirmed that all participants were familiar with the operation method, the survey was started.

2.3. Data Collection: QUMARION

A humanoid input device (QUMARION, manufactured by Celsys, Inc.) was used to record motion images. This humanoid input device operates by manipulating a humanoid model with multiple joints, creating its movements as images on a computer screen. These images can be rotated 360 degrees to view from any angle. The device is equipped with 32 sensors distributed throughout the body. When each part moves, the information is captured in real-time by the PC, allowing users to pose the humanoid image on the PC screen using corresponding 3D animation software. (Figure 1).

First, the participant was asked to reproduce his or her own free-throw motion while manipulating the humanoid input device. In creating the motion video, the participant graded the entire free-throw motion by herself and created a motion video for each point, such as the wrist, head, arm, torso, waist, foot, and entire body. Because the computer images moved in synchronization with the operation of the human input device, the participnts checked the motion and made several revisions, confirming that the images were almost the same as their own motion images, and the video was completed.

2.4. Data Collection: Interview Survey

Data were collected through interviews using the following two methods. First, in the process of creating movement images while operating the human input device, interviews were conducted to confirm the kinds of images being used and how they were expressed for each point, such as the wrist, head, arm, torso, waist, leg, and whole body. The interviews were semistructured in-depth, and open-ended. Next, based on the visualized movement images, we asked the participants what kind of consciousness they had in performing the shooting movement and what kind of body movements they expressed by changing the movement images from various angles, using the stimulus playback method (stimulated recall). In-depth open-ended interviews were conducted in a semistructured manner. In addition, a table was created to show the movements of the computer-generated motion image from four angles (front, back, right, and left) at each stage of the movement. The participants were asked to write reflection notes on the visualized movement images. Based on the notes, in-depth, open-ended interviews were conducted in a semistructured manner using the stimulus playback method (stimulated recall). Semistructured interviews were conducted in-depth using stimulated recall and open-ended interviews based on the notes. In the notes, the participants were instructed to write down what they considered to be important points, evaluate the reproducibility of the movements, and identify unclear images, areas of concern in their own movements, and good areas of their own movements (Figure 2).

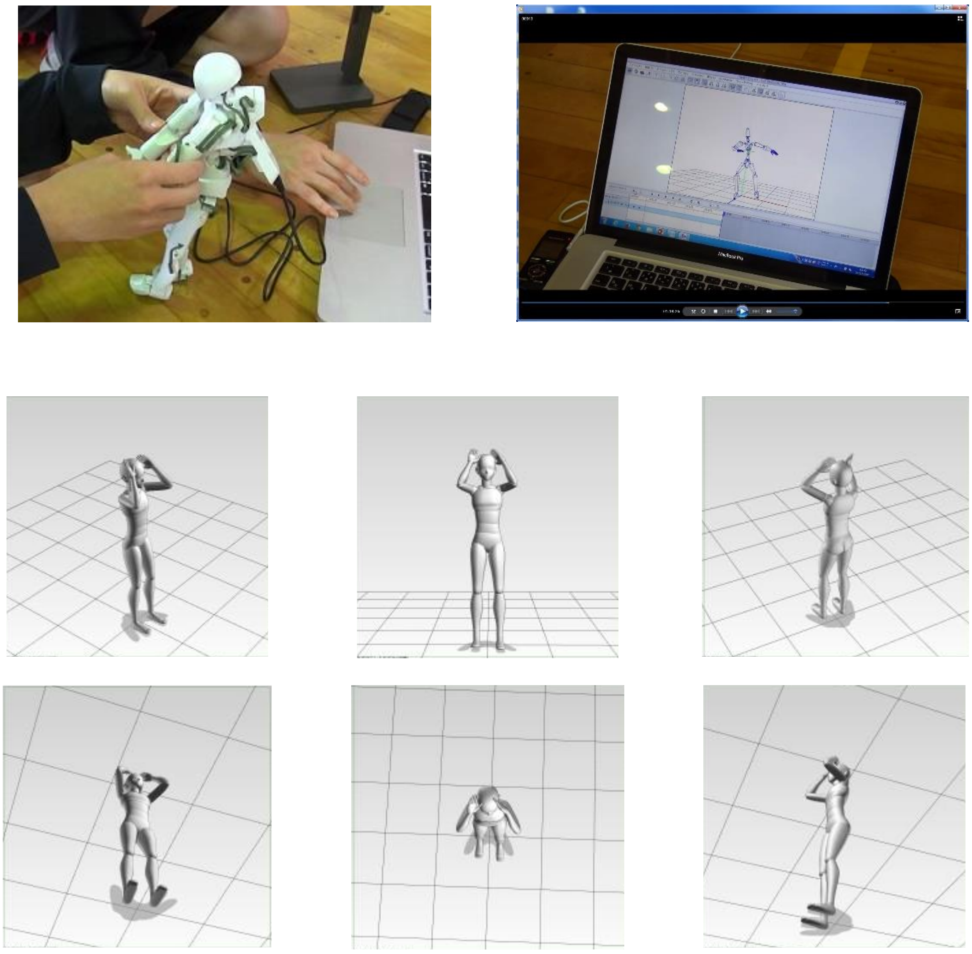

Figure 1. Humanoid input device QUMARION and created images

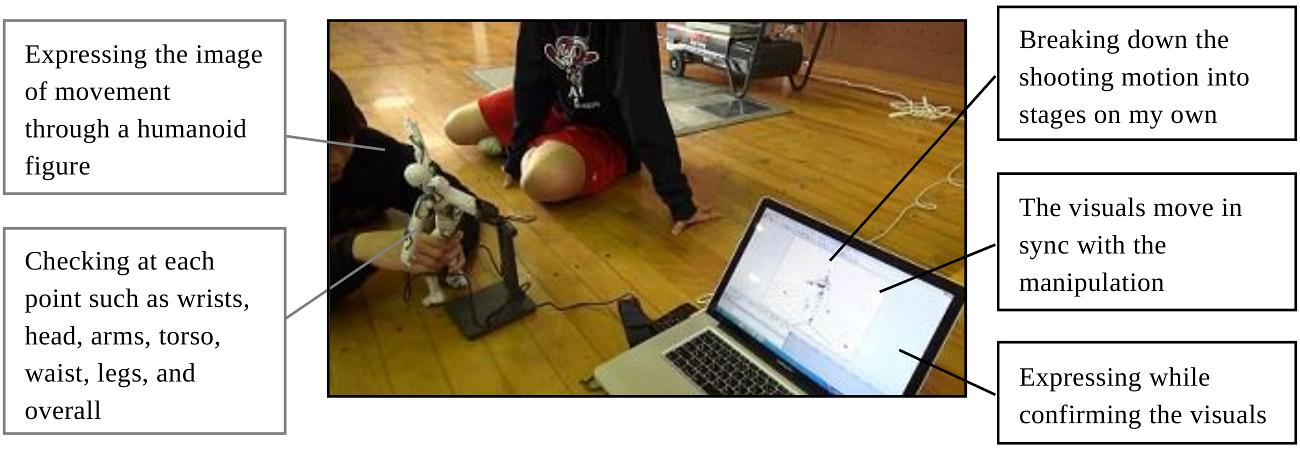

Figure 2. Scene of creating movement imagery

2.5. Data Analysis

The speech data obtained from the interviews were immediately converted into text, and then hierarchical categorization was conducted based on the qualitative data analysis method of Côté et al. (1993) and Patton (2002), with multiple researchers sharing the analysis process.

2.6. Credibility and Certainty

We conducted a study to evaluate the quality of the research based on authenticity (reality of the data) and certainty (whether the data and procedures can be relied upon), as presented below. First, to confirm that the participant's motion image was accurately visualized, we asked the participants to speak while focusing on the key points during the operation of the human input device, which was considered authenticity. Second, to visualize the motion image more accurately, the investigation was conducted in a gymnasium so that the participants could operate the human input device while confirming their actual movements. This enables certainty to be considered. Third, the interviews were conducted in a semistructured manner to ensure the homogeneity of the questions for multiple subjects and to provide certainty in data collection. Fourth, data certainty was ensured by adopting a stimulus replay interview method based on the motion pictures and the motion reflection sheets generated by the participants. Fifth, the process of data analysis was shared by several experts, and the analysis was conducted through multiple discussions to ensure certainty.

3. Results and Discussion

3.1 Motion Images

The participants created their own motion images by dividing the entire shooting motion into several phases (Figures 3–5). Three motion images were created using three groups with three, four, and five motion divisions. Three motion divisions were created by three intermediate high school basketball players (A,B,C), four motion divisions were created by two advanced high school players (D,F) and one proficient professional player (G), and five motion divisions were created by one advanced high school player (E) and five proficient professional players (H to L).

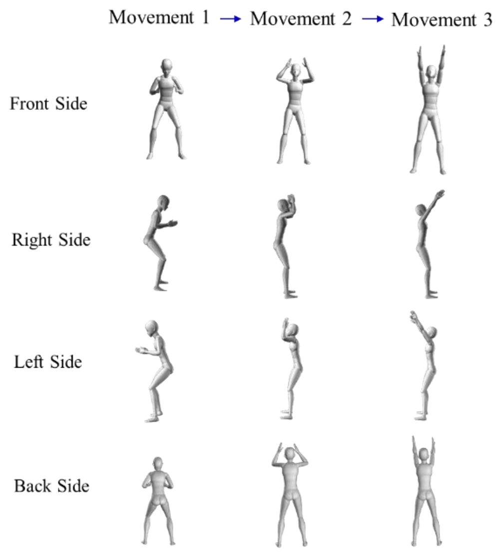

Figure 3. Image of free-throw movement (three motion divisions): Player A

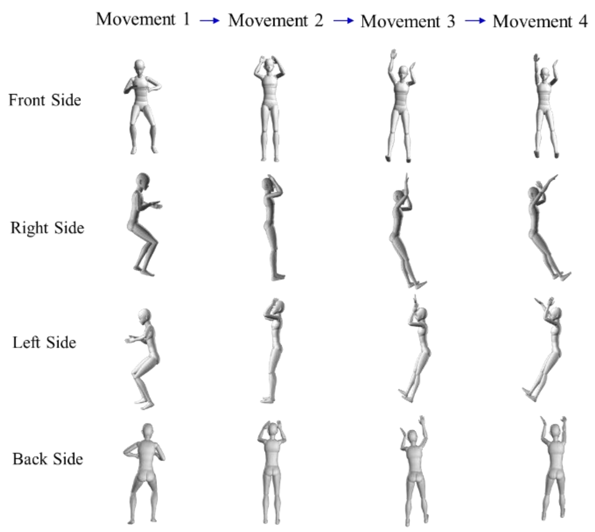

Figure 4. Image of free-throw movement (four motion divisions): Player D

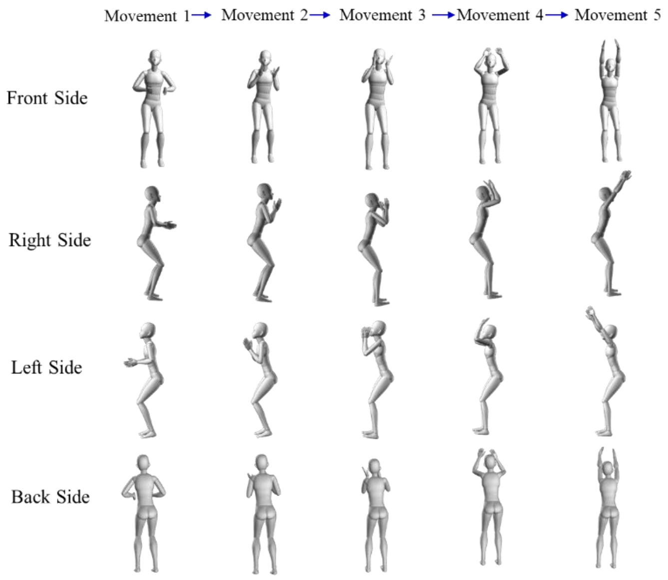

Figure 5. Image of free-throw movement (five motion divisions): Player E

3.2. Motion Image Reflection Memo

In this section, the reflection memo created in the form of writing on the visualized motion image picture is examined.

Figure 6 shows a reflection memo based on the motion image of Player A, who is at an intermediate level of proficiency, with the motion image expressed by dividing the motion into three segments. In the memo, the participant was instructed to write down what she considered important points and areas of concern during her own movements. However, there were few notes on each image, and there were many ambiguous parts in the player's own movement images. The participants were asked to self-assess the extent to which the generated motion imagery accurately replicated various aspects: the shape and position of each body part (spatial elements), the flow of movement (temporal elements), and the specific features of the action (individual elements). Consequently, ambiguous assessments were offered, including expressions such as "it might be," "I believe it resembles something like this," and "slightly leaning forward." Furthermore, comparative evaluations between the actual motion and the generated imagery by other players indicated that while the movements and flow were not perfectly aligned, they were deemed to be quite similar.

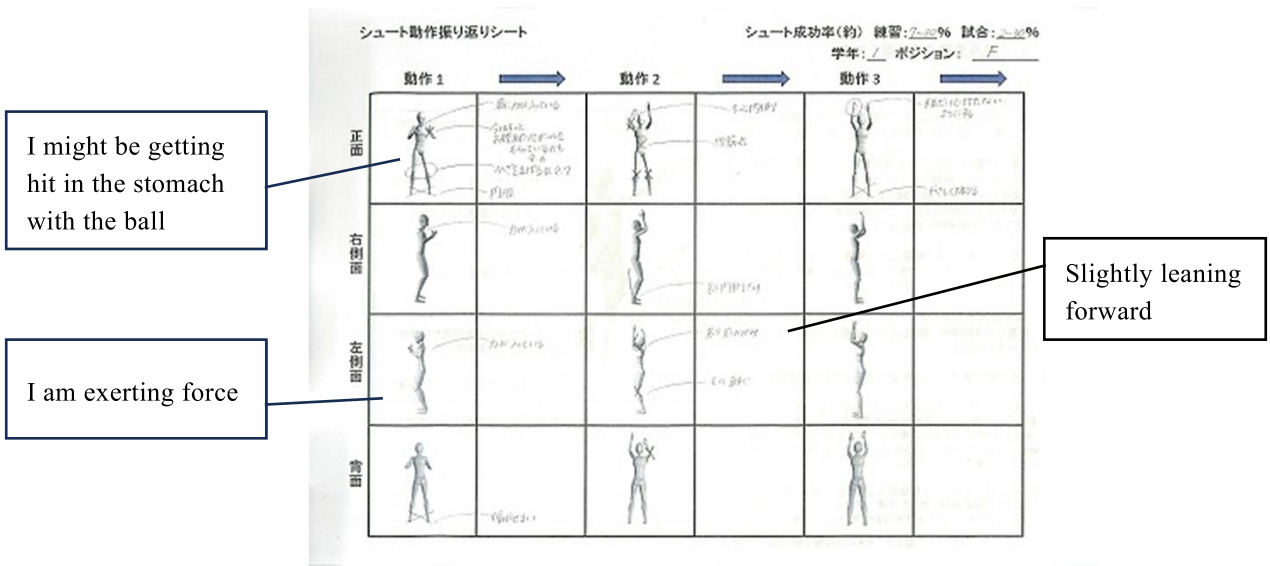

Figure 6. Point review memo based on the motion picture (three motion divisions): Player A

Figure 7 shows the reflection memo of Player D, who is at an advanced level of proficiency, expressing the movement image in the four movement divisions. The memo describes in detail the points of movements that are important to the player and the points of physical movements that she is conscious of in practice and games. In addition, each movement is associated with each of the others, and it can be inferred that the movement image is formed with an awareness of the linkage and flow of the movements. The evaluation was made in an unambiguous manner. Evaluation of reproducibility of action imagery suggests that the participants in all three categories are believed to have a high level of alignment between actual movements and imagined representations. This inference is drawn from statements such as "I think of it as being my true self" and "My movements are reproduced quite accurately," made by all three subjects in this classification. Moreover, descriptions such as "Bringing my right foot forward to avoid arching my body while jumping" and "I always make a conscious effort to keep my right hand in this position" indicate that play is executed with deliberate attention to the body and movements, suggesting a detailed awareness of one's bodily actions. However, expressions like "It might be more internal, if anything" regarding specific details or the state of the body during actual movements suggest that there may be discrepancies between the imagery of actions and the actual sensations experienced during movement. Thus, it can be inferred that there is a possibility that the imagery of actions and the actual movements being felt do not perfectly align.

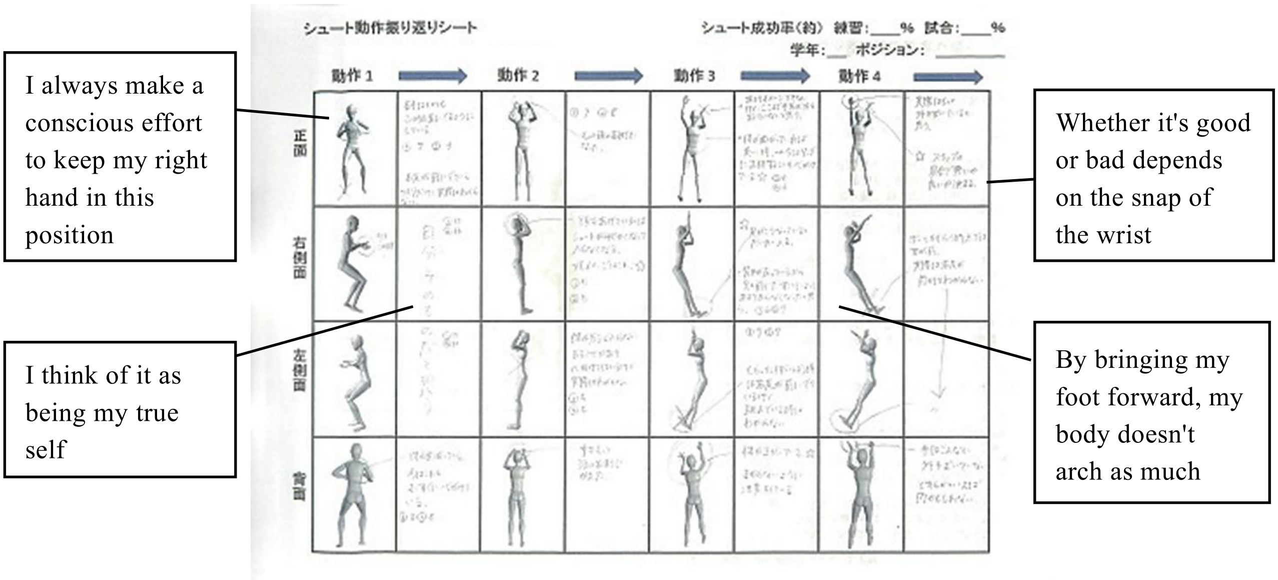

Figure 7. Point review memo based on the motion picture (four motion divisions): Player D

Figure 8 shows the reflection memo of Player E, who is very proficient in expressing the movement image in the five movement segments. In the memo, there are many descriptions of the movements seen from the outside as well as matters seen from the inside and sensory matters felt from the inside. The movement images are handled using both external and internal images. In this group of five divided actions, all players vividly depicted the imagery of shooting movements. Descriptions such as "straighten the body as if pushing the ball up from above the head and extending the knees" and "tighten the buttock muscles, exert firm pressure on the thighs, and synchronize the movements" suggest that they envisioned the sequence of shooting actions while associating them with various bodily movements and gestures. From this, it can be inferred that they possess a high level of self-awareness and perceptual representation formation ability. Furthermore, statements such as "it matches perfectly," "I believe I can express even habits and individuality in detail," and "I feel that not only the form of movement but also the conscious effort to create that form is expressed" indicate that there is minimal disparity between the actual movements and the imagery. Based on the above points, it is believed that the findings support the reports by Tanaka (2000) and Hishitani (1993) , which point out the relationship between the clarity of imagery demonstrated by high levels of self-awareness and proficiency in motor skills. Specifically, it was observed that as proficiency in movement increased, the clarity of imagery improved. This improvement led to an enhanced frequency and capacity to vividly reproduce movements through the body. Consequently, a reduction in the disparity between imagery and actual movements was noted, affirming the relationship between the enhancement of imagery clarity and proficiency. Furthermore, proficient players attribute personal meanings such as habits, strengths, and confidence to their movement imagery, suggesting that cognitive aspects influence movement imagery alongside sensory aspects.

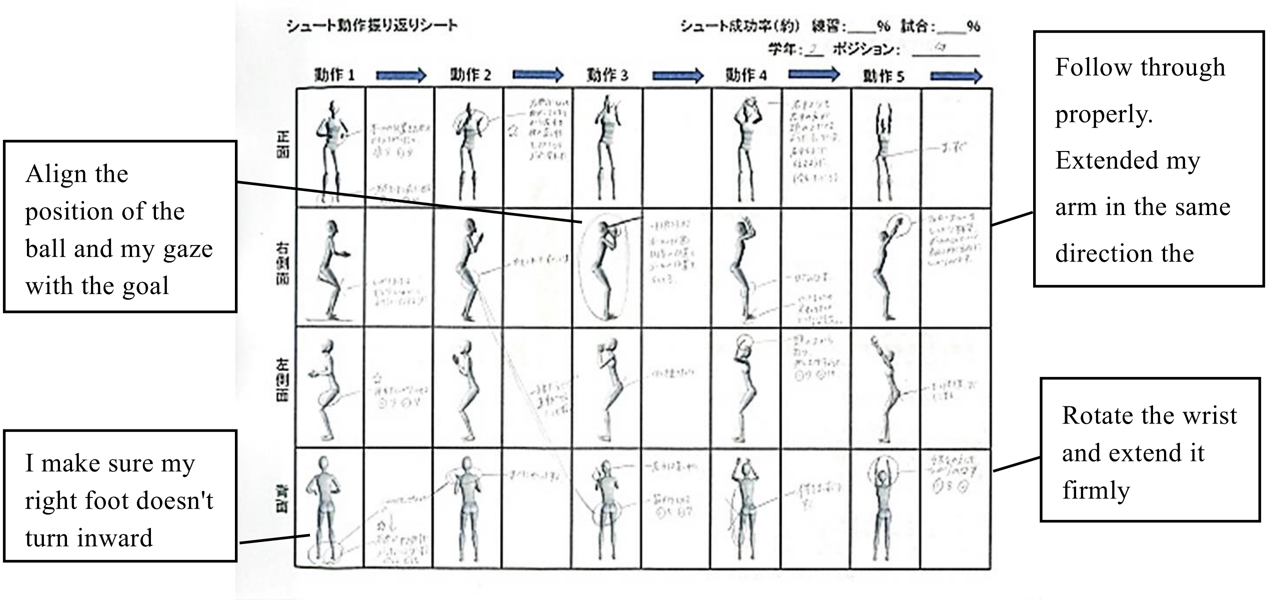

Figure 8. Point review memo based on the motion picture (five motion divisions): Player E

3.3 Analysis of Utterances Related to Action Images

We conducted a qualitative analysis based on the qualitative data analysis method of Côté et al. (1993) and Patton (2002). Specifically, from the textualized utterance data, utterances related to action images were extracted as a single meaning unit, tagged, categorized into subcategories with similar meanings while considering the context of the utterance, and then categorized into subcategories with similar meanings. They were further grouped into categories with similar meanings to create hierarchical categories. The 64 obtained meaning units were grouped into eight subcategories, which were further divided into three categories. Table 1 lists the hierarchical categories.

Table 1. Hierarchical Category and Key Utterance Lists

Category	Subcategory	Speech Example
Confirmation of pre-existing sensations	-Condition of body parts -Good movement awareness -Attention and sensory expression	-I let my wrists flex like this. (L) -I always keep my right hand in this position. (J) -The ball is held in the stomach area. (F)
Check for uncertainties in movement and sensation	-Searching for physical condition -Matching of movement results with kinesthesia	-I don’t know what happens below my ankles when I’m jumping. (G) -I don’t have a good idea of the direction of my wrists. (C)
Correction of sensory discrepancies	-Confirmation of movement at a bad time -Organize movement awareness -Check movement awareness and sense of movement	-I have a habit of bending my body, and I try to do it, but I don’t really know what it is. (D) -When I don’t shoot, my knees are not bent, so I have to be careful. (K)

Confirmation of pre-existing sensations

This category was created to describe the confirmation of body positions and sensations while paying attention to each movement. As indicated by expressions such as “*like this*” and *“around here,”* this category shows the awareness of connecting the state of the body part and the sensation being attended to the image of the action, while capturing it descriptively.

One player described the sensation of releasing the ball as follows; *"At the moment of releasing the ball, I throw the ball as if I push it out with my knees. So I don't really feel like I'm making an action with my hands or arms." (Player B)*

Another player, while recalling and checking the positions of her own body parts, described the body parts she is always conscious of as follows: *"I am always conscious of my right hand coming to this one. So I hope I was able to express that part well with this doll." (Player F)*

These statements suggest that by manipulating the humanoid input device to create images, the participants became conscious of the motion images they had previously held vaguely, to focus on the sensations they already had, to confirm them, and to manifest them in an objectively visible form as images.

Check for uncertainties in movement and sensation

This category was created to indicate awareness of the need to explore and check the state and sensation of one's own body in an attempt to express movement images through the manipulation of a humanoid input device. In this category, an attempt was made to explore the movements of specific parts of the body and the accompanying sensations that are unknown. It can be seen that each movement is related to the others and that the entirety and continuity of the movement, such as the movement of the whole and the flow of the movement, are being considered.

One player described this point as follows:
"I have a sense of what it feels like to jump, but after that, I don't really know. I can feel my knees and ankles, but I don't have a clear image of the angle of my ankles, or the order in which the various parts of my body move. I wonder what's going on." (Player D)

Using the senses that she already has as clues, she is trying to become aware of the connections between the senses in areas where the image is unclear, while being conscious of the relationship between the movements. From these utterances, it can be seen that in the process of making the movement image conscious, a conscious activity to search for sensory cues that are not yet present is taking place.

This is because of the meaning of extending the movement image, and it is presumably important in terms of continuity in image formation or the construction of relationships between individual images. In this regard, Kaneko (2020) pointed out the importance of extending body images from the viewpoint of rehabilitation. This process of conscious image creation is also consistent with Naruse's (1988) concept of intention and effort as important concepts in movement imagery. In other words, movement is a process of active activity in which one strives to realize body movement as intended, which is consistent with what the participants in this study described as "*thinking, doing, and then correcting the action over and over."*

Correction of sensory discrepancies

This category was created to indicate an awareness of checking for discrepancies between the actual movement and the sensation of movement by checking the conscious movement in more detail in the image using sensation as a cue.

One player described the discrepancy as follows; *"I have an image of feeling the weight of the ball in the palm of my hand and then putting all my strength into it. But in reality, I throw the ball quickly, so I feel that my image is a little different from what I am actually doing." (Player L)*

Another player recalls images not only from an external image but also from an internal point of view and matches the actual movement with the motion image from the perspective of the motion image felt from the inside: *"When I do not shoot, my knees are always extended, so when I imagine the movement, I draw an image of bending my knees. When I visualize the movement, I imagine my knees bending. This gives the image a three-dimensional feel."* (Player H)

These statements indicate that it is important for athletes to have a movement image from the objectified third-person perspective as well as the movement image from the first-person perspective as the participants in the movement, and the ability to recall the image from both perspectives in the process of creating the movement image leads to a clearer image. The process of creating motion images suggests that being able to recall images from both perspectives leads to clearer images. This point overlaps with that of Yamada et al. (2021), who pointed out that motor images experienced as simulations of actions are important for motor learning.

5. Conclusion

In this study, we visualized the motion images drawn by players by reproducing their motion images on a computer using a humanoid input device. Then, we examined the influence of such visualizations on players' understanding and acquisition of movement skills. The results show that the elaboration of the motion image tended to increase with the degree of proficiency in the free-throw shooting motion. In addition, it was shown that the extension from an individual action to the whole action, relevance, and diversity of the viewpoint of the image also changed according to the level of proficiency. In addition, it was suggested that the effort to visualize the movement image promotes metacognitive activities for one's own movement in the image formation of the chute movement, thereby deepening the analytical and individual sensory understanding of the movement and at the same time promoting the image formation relating the entire movement.

Author Contributions

Conceptualization, K.K. & Y.M; methodology, K.K.; validation, K.K. & Y.M.; qualitative data analysis, K.K. and Y.M.; investigation, K.K. and Y.M.; resources, Y.M.; writing—original draft preparation, K.K.; writing—review and editing, K.K.; visualization, Y.M.; supervision, K.K.; project administration, K.K.; funding acquisition, K.K

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Institutional Review Board Statement

The study was conducted according to the Declaration of Helsinki.

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

This paper builds on and enhances the author's 2015 presentation at the 66th Conference of the Japan Society of Physical Education, Health, and Sports Science.

Appendix

Scene of operation image creation

The process of creating an image using a humanoid input device

Operation of humanoid input devices

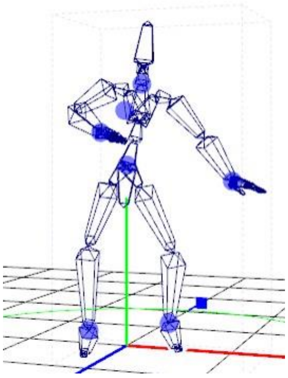
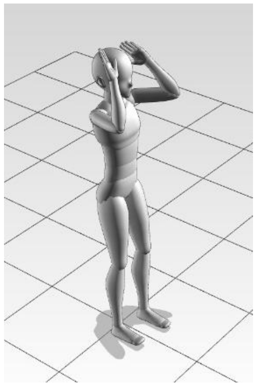


Image of movement created by line drawing



Motion picture with human figure

References

Annett, J. (1995). Motor imagery: Perception or action? *Neuropsychologia*, *33*, 1395–1417.

Cooley, S. J., Williams, S. E., Burns, V. E., & Cumming, J. (2013). Methodological Variations in Guided Imagery Interventions Using Movement Imagery Scripts in Sport: A Systematic Review. *Journal of Imagery Research in Sport and Physical Activity*, *8*(1), 1–22. https://doi.org/10.1515/jirspa-2012-0005.

Côté, J., Salmela, J. H., Baria, A., & Russell, S. J. (1993). Organizing and interpreting unstructured qualitative data. T*he Sport Psychologist, 7*(2), 127–137.

Dickstein, R, Dunsky, A., & Marcovitz, E. (2004). Motor imagery for gait rehabilitation in post-stroke hemiparesis. *Physical Therapy*, *84*(12), 1167–1177.

Hasegawa, N., & Hoshino, K. (2001). The Effect of "Dousa-Hou" on experience imagery. *Journal of health and sports science Juntendo University*, *5*, 133–139.

Hishitani, S. (1993). Imagery differences: What controls the vividness of imagery?. Advances in Japanese Cognitive Science, 7, 81-117.

Holmes, P. S., & Collins, D. J. (2001). The PETTLEP approach to motor imagery: a functional equivalence model for sport psychologists. *Journal of Applied Sport Psychology, 13*(1), 60–83. https://doi.org/10.1080/10413200109339004

Kaneko, F. (2020). Development of a rehabilitation system using VR to feed back kinesthesia. *Measurement and Control*, *59*(1). 37–40.

Kitamura, K. (2011). The Action of "Work Language" from the Viewpoint of Proficiency: Learning through the Sharing of Sensations Leading to Flow Experiences. In *Waza Gengo*. Keio University Publisher, 33–63.

Kitamura, K., Saito, S., & Nagayama, T. (2005). How do expert coaches enhance Athletes' and Team Performance? Construction of a Coaching Mental Model of Expert High School Soccer Coaches in Japan. *Journal of Sport Psychology*, *32*(1), 17–28.

McAvinue, L. P., & Robertson, I. H. (2008). Measuring motor imagery ability: A review. *European Journal of Cognitive Psychology, 20*(2), 232–251. https://doi.org/10.1080/09541440701394624

Miyazaki, K. (1980). Is mental image a picture or a proposition? *Japanese Journal of Educational Psychology*, *19*, 112–124.

Morris, T., Spittle, M., & Watt, A. P. (2005). Imagery in sport. Champaign, IL: Human Kinetics.

Munroe-Chandler, K. J., Hall, C. R., Fishburne, G. J., Murphy, L., & Hall, N. D. (2012). Effect of a cognitive specific imagery intervention on the soccer skill performance of young athletes: Age group comparisons. *Psychology of Sport and Exercise*, *13*, 324–331.

Naruse, G. (1988). Self Control method. Tokyo: Seishin Publisher.

Patton, M. Q. (2002). Qualitative evaluation and research methods (2nd ed.). Newbury Park, CA: Sage.

Tanaka, M. (2000). Analysis of verbal-name coding and image-coding in turn skill, Ehime University Faculty of Education Bulletin, 46(2), 135-148.

Yamada, H., Tanaka, S., Kimura, T., & Kaneko, F. (2021). Connecting Scientific Knowledge to Sports Skill Improvement - Biomechanisms of Sensory Motor Learning. *Journal of Biomechanical Society*, *45*(2), 71–74.

Williams, S. E., & Cumming, J. (2011). Measuring athlete imagery ability: The Sport Imagery Ability Questionnaire. *Journal of Sport & Exercise Psychology, 33*(3), 416–440. https://doi.org/10.1123/jsep.33.3.416

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Article

Research for Supporting Tactical Analysis Concerning Pass Skeleton in American Football

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Abstract
The authors have been conducting researches on the measurement and analysis of athletes, things and events in field sports. In particular, we focused on American Football which is the most intelligent and complicated sports, and carried out the possibility of matchup analysis of its pass play. Based on the past researches, it was found that it was possible to estimate success or failure for each play by applying to the time-series trajectory image data of pass matchup players using the CNN（Convolutional Neural Network）. However, it is necessary to improve versatility by supporting pass skeletons considering not only one-on-one defense but also formation of zone defense that are close to the match format. Therefore, we aim to support the analysis of pass skeletons, which had to consider huge parameters such as the position and movement of each player from the start of play to the success or failure of the pass. The research was carried out based on a hypothesis that the success or failure of a pass from the position several seconds before the origin of the QB pass throw could be determined by taking into consideration the skill that is the compatibility of each player, the positions and the movement trajectory of the receiver team（WR, TE, and RB）, and the defenders（LB, DB, S）that mark them. As a result, the success rate and failure rate of the assumed pass player could be predicted by using the position and its trajectory image of each player from 3 seconds before the pass pitch. And then, by determining that the pass to the maximum likelihood receiver is optimal, we confirmed that useful information can be provided to support strategy planning during the game and guidance during practice.

Keywords: American Football, Pass Skeletons, Support of Tactical Analysis of Pass Play, Trajectory Image Data, CNN(Convolutional Neural Network), Prediction for Success or Failure of Pass

1. Introduction

Japan Sports Agency (Ministry of Education, Culture, Sports, Science and Technology, 2023b) is promoting support for the success of Japanese national players from a scientific aspect as a priority policy for improving the international competitiveness of Japanese athletes(Ministry of Education, Culture, Sports, Science and Technology, 2023a). This intends to utilize not only ICT (Information and Communication Technology) and IoT (Internet of Things) but also data science. In particular, analysis for player performance and game conditions using quantified numerical values is required. However, these attempts in the field of sports stand at the dawn. In addition to expertise in sports competitions, advanced ICT/IoT operation techniques and data science knowledge are also required. Therefore, it is an urgent issue to increase the number of specialists well informed of the expertise in these areas.

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Two of the authors were American football players during their school years. It is not too much to say that coaching in this sport still relies on the experience and intuition of managers and coaches. Recently, though they have come to obtain Stats information of the team and individuals by visually checking the video images captured by video cameras or using dedicated software that enables tagging of video data(Hudl, 2025), advanced data analysis has not been conducted. Thus, we came up with the idea of improving team performance by making full use of ICT/IoT/AI, which have made remarkable progress in recent years, for American football of which the game progresses based on intelligent and complex strategies.

American football is a kind of sports played by 11 players each in the OF and DF; the OF aims to make a touchdown by carrying the ball to the opponent's end zone in run or pass plays, while the DF is responsible for stopping the OF from doing so. In a game, one play lasts about 10 seconds before the OF is stopped by the DF on every down. The OF and DF teams change when the OF side fails to advance more than 10 yards within the maximum of 4 plays, In particular, the phase often changes dramatically when a successful pass play is made. Therefore, it is important to analyze the movements of the receivers including the QB on the OF side, WR, TE that are both the line and receiver, and RB; the LB on the second string defending the offence of the opponent team on the DF side; the DB on the third string; and the defenders of S.

There are three types of pass-play practice formats: scrimmage, pass skeleton and matchup. A scrimmage is a match-style practice of 11 OFs and 11 DFs on pass and run plays in real-game situations. A pass skeleton is a practice of pass plays without an offensive line (OL) or defensive line (DL) (mainly the defensive formation in a zone defense). And a matchup is a practice of a one-on-one man-to-man defense between the WR and the DB. Matchups are a form of one-on-one, man-to-man defense practice between WRs and DBs. The authors have conducted the research with the long-term goal of analyzing scrimmages, the medium-term goal of analyzing pass skeletons, and the short-term goal of analyzing matchups.

As a first step of our research, we interviewed managers and coaches in the field to find out what kind of items they have been seeking, of which results were roughly classified into four categories (Table 2 in the existing research(Yamamoto, Y., et al., 2018)). Most of them were matters for which quantitative information was required. In particular, focusing on tactical planning to gain an advantage in a game and analytical support for repeated practice of strategies for that purpose, the typical sub-items (1, 4, 7, 12, and 14) can be summarized as follows.

1) Acquisition of tracking information on the players and the ball
   Sub-item 1) Grasping the position of the players and the distances between them
2) Classification and recognition of plays
   Sub-item 4) Confirmation by reproducing the formation and movements as instructed
3) Formation Analysis
   Sub-item 7) Acquisition of information on formation and Stats of the opponent team
4) Evaluation of player performance
   Sub-item 12) Grasping the compatibility between players on pass plays (e.g., trust between the quarterback (QB) and receivers, or receivers' awareness that it is hard to deal with the defenders)
   Sub-item 14) Predicting the success and failure rates of the play in case that the formations and the movements of the players of one's own team and the opponent team were obtained

Therefore, the authors have studied methods to satisfy the need in the first main item (Acquisition of tracking information on the players and the ball), which is the greatest core in two approaches. In the first approach, we have discussed possibility of not only visual check made by the manager, coach and players using images taken by the video camera but also their grasping of the positioning of the players, their running courses, and tactical formation as a whole(Jiang, W., et al., 2018; Tanaka, S., et al., 2020). The advantage of this method is that it allows acquisition of information not only about their own team but also about the opponent team. However, due to the nature of American football, it is difficult to accurately identify the locations of players, distinguish them from each other, and track their movement since occlusion occurs because multiple players play closely together.

Recently, on the other hand, as sensing technologies for athletes, things, and events have attracted more attention, IoT devices have become available at affordable prices just like video cameras. Thus, in the second approach, we have been conducting visualization and quantitative evaluation of American football players' play(Yamamoto, Y., et al., 2018) using the Global Navigation Satellite System (GNSS) sensor "SPI HPU (hereinafter referred to as GPSports)" (4Assist, Inc., 2023), with our focus on its capability of recognizing and tracking players with ease. We have confirmed that the success rate of plays based on the compatibility between players for passing plays agrees with the success rate of plays based on the level of skill (regular or semi-regular) of the players as judged by managers and coaches based on their experience. This shows that the skill and compatibility of players are two sides of the same coin, and that by considering the ability (skill) of each player, it is possible to quantify and analyze the compatibility, such as the ease or difficulty of playing together caused by the combination of players, allowing acquisition of information that coaches want to know and information that is useful for players to review their play. In addition, in soccer, we have also made interviews in the field, As a result, in addition to acquiring numerical data such as running distance and speed, we have conducted a piece of research for visualizing players' positioning and grasping the ball retention rate(Jiang, W., et al., 2019).

By using this visualization system(Yamamoto, Y., et al., 2018), we were able to establish a foundation for in-depth research on sub-items 1, 4, 7, and 12, which are required by managers and coaches in the field. However, regarding the real-time performance, our research was conducted on the assumption that the communication environment and the functions of communication speed and data volume would improve in the future.

As the next phase, we focused on the sub-item 14, the determination of success and failure. In American football, tactics are constructed from several hundred different plays, and the choice of strategy has a significant impact on the victory or defeat of a game. If a versatile tactical analysis method can be established, it will provide an opportunity to reconsider tactics such as judging the timing of player change, changing play calls, and estimating plays. For this reason, we have paid attention to deep learning and have investigated the automatic acquisition of important information regarding tactical analysis from the characteristics of play by learning measurement data from practice matches and during daily practice. Focusing on passing play, which is the most exciting part of play of the game, we have conducted research with the goal of realizing a new analysis method of supporting tactical planning by estimating the success or failure of a pass, taking into account the skill (compatibility) of players(Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020).

Therefore, we applied CNN (Convolutional Neural Network) to the trajectory image data of American football pass plays to attempt matchup analysis of the offense (OF) and the defense (DF) (Yamamoto, Y., et al., 2020). Specifically, we verified whether it would be possible to construct a deep learning device for determining the success or failure of a pass play using trajectory image data. As a result, it was found desirable to be able to support the method of detecting the strategy during the play of the assumed game as well. Then, we investigated a method for judging not only the trajectory image of the result of play, but also the situation during a single play, which changes from moment to moment(Tanaka, C., et al. 2020). In specific, we verified the estimation accuracy of the success or failure of a pass by play classification, taking into account the chronological changes in the trajectory information of the players using CNN. As a result, it was confirmed that it is possible to make a matchup analysis in the middle of playing man-to-man defense assuming only the QB, the wide receiver (WR), and the defensive back (DB), allowing to provide useful information to coaches at the actual game level. Two issues have remained that it is not realistic to measure all of the pass plays for each play category and that only match-up plays are covered, both of which are difficult to solve at the same time. It is because the number of combinations of pass patterns becomes enormous when extended to a pass skeleton except OF and DF line members, and that it is almost impossible to reproduce the exact same play as it takes zone defense formation with defensive members including linebackers, DBs, and safeties (S). Furthermore, since the tactical analysis technique is applied to college football, where personnel turnover is frequent, the players of both one's own team and the opponent team change over a certain period (four years), and consequently the tactics that can be adopted each year are fluid according to the abilities of the players. In addition, because of using the data collected in the first several seconds after the play starts, it is difficult to instantly suggest who is the best target for a pass at any given point after the play starts.

Therefore, with a focus on overcoming these issues, this research aims to predict the success and failure rates of pass in pass plays in the pass skeleton by proposing a versatile analysis method that deals with only the information obtained during the first several seconds of a play, while utilizing a small amount of data obtained from the active players and avoiding being limited by the type of play. In specific, regarding the analysis of the pass skeleton, which conventionally has required consideration of a huge number of parameters such as the position and movement of each player from the start of play to the success or failure of the pass, we conduct a piece of research based on a hypothesis that, setting the time of pass throwing by the QB as the origin point, the pass to the receiver with the maximum likelihood can be determined to be optimal, by taking into consideration the positions and movements of the receivers including the WR, the tight end (TE), and the running back (RB), together with those of the defenders (LB, DB, S) who are marking them, from several seconds before the origin point, as well as the skill (compatibility) of each player which can be inferred by whether both of them are regular players or a combination of regular and semi-regular players.

We work for achieving estimation of success or failure of passes based on the positional relationship between the WR and DB at the time the QB throws a pass, which was difficult to achieve in the existing research(Tanaka, C., et al. 2020), and establishing a versatile tactical analysis method for providing the field members with materials that allow them instantaneous decision making of tactics during a game.

2. Related Research on American Football and Positioning of This Research

2.1. Research on Existing Researches

Although there are some examples of ICT applications to American football using IoT devices here and there, most of them are mainly based on video processing and have the same problems of accuracy due to occlusion as in the authors' attempts(Jiang, W., et al., 2018; Tanaka, S., et al., 2020). First, we take a general view of the contents of related researches along the following items: 1) player and ball tracking(Hayashi, M., et al., 2013; Chen, S., et al., 2015; Kurano, J., et al.., 2013; Kurano, J., et al.., 2015; Arumugam, D., et al., 2013; Catapult, 2023), 2) classification and recognition of play (Intille, S., et al., 1999; Li, R., et al., 2010; Varadarajan, J., et al., 2013; Swears, E., et al., 2012; Chen, S., et al., 2014), 3) understanding formation and its analysis(Tani, T., et al., 2014) and (Atmosukarto, I., et al., 2013), and 4) player performance analysis (Beckwith, G., et al., 2019; Bruke, B., 2019; Dutta, R., et al., 2020; Laviers, K., et al., 2014; Molineaux, M., et al., 2009; Takayanagi, R., et al., 2020; Lee, N., et al., 2016); and then clarify their differences from this research.

2.1.1 Player and Ball Tracking

The researches on player and ball tracking (Hayashi, M., et al., 2013; Chen, S., et al., 2015; Kurano, J., et al.., 2013; Kurano, J., et al.., 2015; Arumugam, D., et al., 2013; Catapult, 2023) can be roughly divided into two types: researches focusing on players (Hayashi, M., et al., 2013; Chen, S., et al., 2015) and researches limited to balls(Kurano, J., et al.., 2013; Kurano, J., et al.., 2015; Arumugam, D., et al., 2013; Catapult, 2023).

The research(Hayashi, M., et al., 2013) on player tracking examines the possibility of tracking by learning HOG (Histograms of Oriented Gradients) feature vectors of players. The research(Chen, S., et al., 2015) proposes a tracking method for dealing with player occlusion by calculating the optimal solution using linear programming based on the number of players detected in the previous frame. However, these researches are still difficult to apply to play analysis due to a problem of accuracy caused by image processing.

The researches on ball tracking(Kurano, J., et al.., 2013; Kurano, J., et al.., 2015; Arumugam, D., et al., 2013; Catapult, 2023) propose methods for tracking the ball using player tracking information. In American football, there are two types of OF attacks: pass plays and run plays, and methods have been proposed to deal with each of them. For example, in the research(Kurano, J., et al.., 2013), the ball is detected using color information for pass plays. When the ball cannot be detected, the previous movement vector is used to estimate its position. Also, in the research(Kurano, J., et al.., 2015), for run plays in which the ball is difficult to detect, the section where the ball could not be detected is interpolated by determining the start and end positions of the play as well as the ball carrier. From another practical point of view, the research(Arumugam, D., et al., 2013) has been conducted to obtain the trajectory and status of the ball using wireless communication technology. Signals transmitted from a wireless communication unit built into the ball are received by the antenna on the field to identify the position of the ball. One product that uses such technology is Catapult Sports' SmartBall(Catapult, 2023), which is designed for soccer balls. Although ball tracking is excluded from our research subject in a series of our researches at this time, we recognize that it is such a subject that should be required to research without exception.

2.1.2 Classification and Recognition of Play

In the researches on classification and recognition of play (Intille, S., et al., 1999; Li, R., et al., 2010; Varadarajan, J., et al., 2013; Swears, E., et al., 2012; Chen, S., et al., 2014), OF plays are classified based on the movement trajectories of players obtained by image processing. It is expected that this will allow managers and coaches to efficiently grasp formations and their movement patterns and trends, and also to be utilized for play classification and recognition of the opponents' OF.

The research(Intille, S., et al., 1999) proposes a probabilistic model to recognize actions of a large number of players. The research(Li, R., et al., 2010) proposes a probabilistic model for classifying types of play by tracking players. The research(Varadarajan, J., et al., 2013) classifies plays using template matching from players' trajectories, and the research(Swears, E., et al., 2012) also attempts to classify plays by learning players' trajectories. In the research(Chen, S., et al., 2014), the position of a play is inferred not only from the trajectory of the players but also from recognition of white lines, which is useful in play classification.

These researches focus on determination and classification of the types of play by using the position and movement trajectory of the players. Consequently, they do not go as far as determination of whether a play is good or bad, which is the goal of the authors.

2.1.3 Formation Analysis

The researches on formation analysis(Tani, T., et al., 2014; Atmosukarto, I., et al., 2013) include an attempt to develop a visualization system of discovering trends for planning tactical analysis from measurement data obtained in past games(Tani, T., et al., 2014), and a piece of research on automatic recognition of OF teams to determine their formation(Atmosukarto, I., et al., 2013).

The research(Tani, T., et al., 2014) aims to search and visualize similar plays in the past by entering information such as the number of downs, remaining distance, hash (ball position) formation, and play type, on the assumption that play data has been accumulated. However, it is difficult to evaluate plays quantitatively only by searching past plays. The research(Atmosukarto, I., et al., 2013) uses image processing to identify player positions and visualize the scrimmage line and formation.
Focusing on analyzing formations by using the past stats information, these researches do not estimate the quality of play as in the previous section, which is the goal of the authors. In addition, there is a problem with the accuracy of the visualization due to issues with estimating the position of players by image processing.

2.1.4 Player Performance Evaluation

The researches on player performance evaluation(Beckwith, G., et al., 2019; Bruke, B., 2019; Dutta, R., et al., 2020; Laviers, K., et al., 2014; Molineaux, M., et al., 2009; Takayanagi, R., et al., 2020; Lee, N., et al., 2016) can be roughly divided into two types: player evaluation(Beckwith, G., et al., 2019; Bruke, B., 2019) and application to tactical analysis(Dutta, R., et al., 2020; Laviers, K., et al., 2014; Molineaux, M., et al., 2009; Takayanagi, R., et al., 2020; Lee, N., et al., 2016).

The former aims to evaluate players' skills using their position and trajectory as well as play data. For example, The research(Beckwith, G., et al., 2019) presents overall performance by collecting personal information such as a player's height and weight, ability information such as speed, and stats information such as the number of touchdowns. The research(Bruke, B., 2019) evaluates quality of the QB based on the action of the QB by having the images of passing moments learned. Thus, both researches did not attain prediction of plays.

The latter provides advantageous information for tactical analysis by analyzing the formations of its own and opponent teams. It also aims to predict the actions of players and teams divided into two types of teams: the OF team and the DF team, and to plan optimal tactics. For example, in the research(Dutta, R., et al., 2020), the trajectory of the DF team viewed from the OF side is used to predict and visualize the pass-coverage probability. The research(Laviers, K., et al., 2014) also predicts the resulting reward (yards gained) based on the trajectory of the opponent player by recognizing the play of the DF in order to evaluate the tactics of the DF. Also, in the research(Molineaux, M., et al., 2009), a method is designed to improve the learning efficiency to achieve the support for the OF action (yards gained) based on the number of defenders and their skills by recognizing the play of the DF. In the research(Takayanagi, R., et al., 2020), based on information such as the position of the plays of the OF and DF as well as the number of downs, a Q-Learning simulation model is used to calculate the reward value of the action depending on to which receiver the QB passes or scrambles and switches to a run play. Consequently, an optimal action pattern is presented. On the contrary, the research(Lee, N., et al., 2016) predicts the play patterns of the WR chronologically from the DF side.
These researches are very similar to what the authors are aiming for. However, they do not take into account the compatibility between the players on the team (sub-item 12), nor do they predict the success and failure rates of the concerned pass play. Therefore, it can be said that these related researches have not yet achieved the goal of sub-item 14).

2.1.5 Discussion of Differences from the Related Researches

The related researches can be summarized as the following needs of 1) accurate tracking of players and balls, 2) easy acquisition of game stats and statistical data of plays, 3) checking whether or not formations and movements have been reproduced as instructed, and 4) obtaining player movements and evaluations of their own and opponent teams.

These are consistent with the results of interviews with managers and coaches, and it can be said that there is the same tendency in many researches. However, the following problems remain.

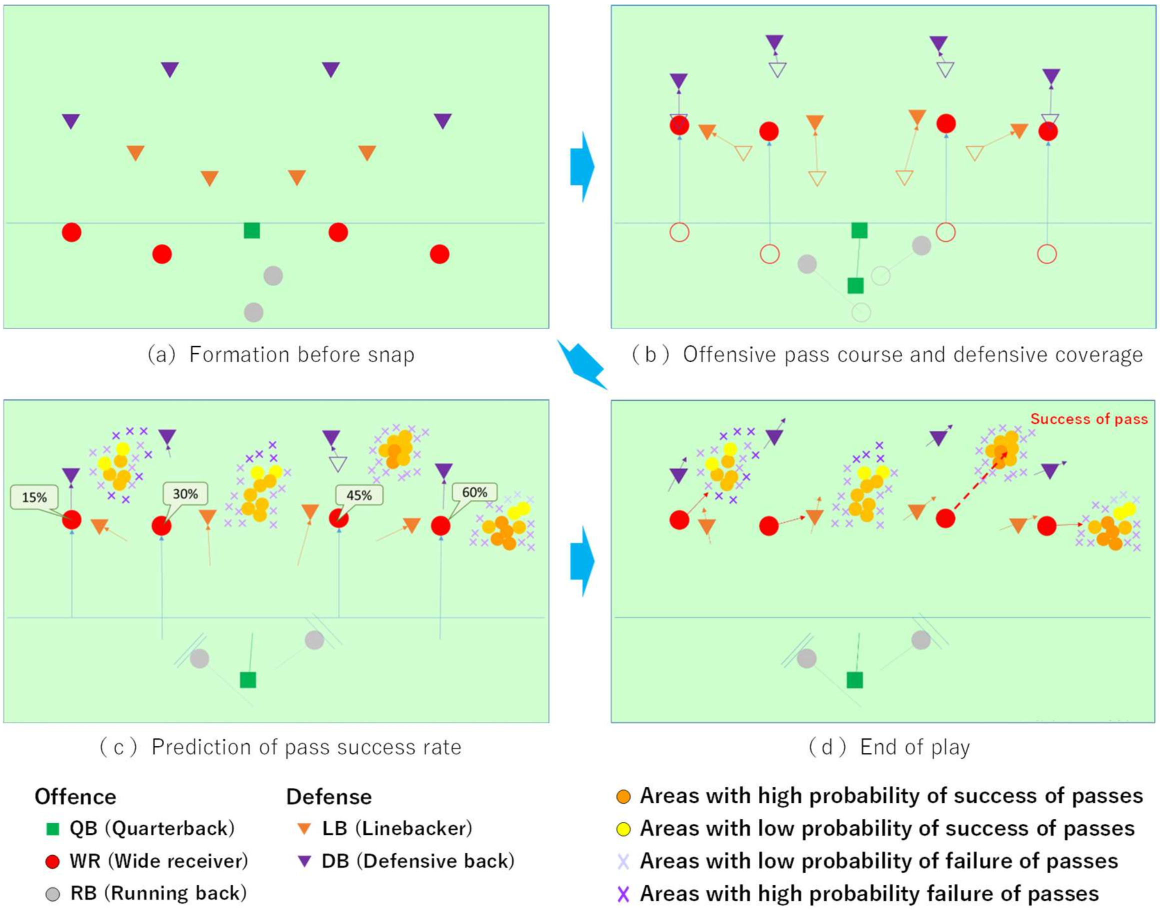


Figure 1. Predicting success or failure of pass skeleton

- The results of the analysis lack accuracy because the analysis is limited to that from videos, which cause a large number of problems with tracking accuracy.
- Accuracy of the position of the players and their distances from each other are not ensured. Furthermore, the analysis does not take into account the degrees of skill (compatibility) of the players.
- Prediction of success and failure rates of the pass skeleton in Sub-item 14) is not realized.

Therefore, the related researches do not guarantee the accuracy of the results of the play analysis, and it is difficult to say that they have been able to implement the needs of the managers and coaches with high accuracy that the authors are aiming for. Furthermore, it is considered that there are no researches that have realized sub-item 14) that take account of sub-items 1, 4, 7, and 12.

2.2 Necessity of This Research

The current phase of our research is still limited to analytical support for matchups(Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020). In the case of assuming a pass skeleton, as shown in Figure 1(a), the play patterns that are developed from the offensive formation of the QB and receivers (WR, TE and RB) are a combination of multiple pass plays and are very complex and varied. In addition to the man-to-man defense, there are also numerous defensive formations of zone defense (LB, DB, S), depending on the play patterns of OF. In specific, it is desirable to be able to predict the areas of successful and unsuccessful passes in Figure 1(c) from the position of the receivers catching the pass and that or defenders in seconds after the position of Figure 1(b), taking into account the OF formations and play calls (play types) shown in Figure 1(a) and the defensive formations of the DF. Based on the difference from the play result of Figure 1(d), if this makes it possible to present the materials for instantly determining whether there is DF in the pass course of the receiver, in which area it is easy for the receiver to catch the ball, and in what timing the QB should make a pass, and most importantly, who is the optimal target in consideration of the skill level (compatibility) of the players, this will lead to "new insights" and thus bring advantageous information to the field.

3. New Proposal to Support Pass Skeleton Analysis

3.1 Significance of Proposal

As the first step(Yamamoto, Y., et al., 2020), we analyzed the success or failure of passes of matchup by the QB, WR and DB by considering the tracking information of the completed play and the skill level (chemistry) of each player. As the second step(Tanaka, C., et al. 2020), we determined the success or failure of the passes during play by using the information from the chronological movement history. These researches have indicated that support information for matchup analysis, which is our short-term goal, can be provided.

Therefore, this research aims to extend to the pass skeleton, which is our medium-term goal. In supporting pass skeleton analysis, there are three types of information that instructors are seeking quantitatively: 1) Whether or not there is a point and timing for QB to throw a pass for each pass pattern, and timing for the receivers that become targets including the WR, TE, or RB to take the course and catch the ball with time to spare. 2) Confirming the area that is covered or to be covered by mapping the movements of the receivers and the defenders including the LB, DB and S. And 3) the determination criteria of the QB prior to release, changes in the movement of the defenders at the time of release, and the positional relation of respective players just before the play is decided and its outcome. In addition, the skill level (compatibility) of each player inherent in these three items is very important. Taking all of these factors into account, it is significant to estimate comparison of the course for the receiver to take when making a successful pass with that for an unsuccessful pass, the defender's response at that time, and the success and failure rates of the target receiver's passes.

3.2 Problem of Proposal

Furthermore, since the subject of this research is college football, unlike semi-professional teams, various adverse effects occur. Specifically, the first team (regular) consists of about 10 OF and 10 DF players respectively, and the second team (semi-regular) consists of 20 to 30 players respectively. However, 25% of the team members are replaced every year. Moreover, since the offensive and defensive rotations are frequent in American football as its playing characteristics, players may change for every play depending on the tactics. Therefore, the time that the OF is on offense in a game is about one hour. However, as half of these plays are run plays, which are not included in this research, it is necessary to develop a technology that can be used even with a small amount of data.

3.3 Overview of Proposal

In order to build a model that predicts the success or failure of a pass, the authors investigated a method(Tanaka, C., et al. 2020) for generating trajectory images (Figure 2, left) as learning data from the movement history of all players according to play classification. Specifically, the study focused on determining the optimal patterns for the color, width, and length of the trajectories. However, In the method(Tanaka, C., et al. 2020), it is very difficult to obtain the success/failure rates of countless pass plays for each receiver, as shown in Figure 1(d). Therefore, we propose a method that focuses only on the information about the few seconds preceding the pass timing during the play (Figure 2 right) so that it is not limited by the play classification (play type). There is no need to classify the plays because the proposed method uses trajectory images of a certain number of seconds from the pass timing during the play. Furthermore, estimation is made by extracting the trajectories of the QB, the target WR, and the DB that mark them out of the trajectories of the players participating in the play, there is no need to ask whether it is man-to-man defense or zone defense, making the method highly versatile that deals with pass skeleton. At the same time, it is a method that kills two birds with one stone as it can predict the success and failure rates of a pass play. Therefore, regarding the analysis of the pass skeleton, which conventionally required consideration of a huge number of parameters such as the position and movement of each player from the start of the play to the success or failure of the pass, particularly as to the prediction of the success or failure rate of the pass in the pass play in Figure 1 (c), based on the hypothesis that it is possible to determine it by taking account of the positions and movements of the receivers from several seconds before the origin point, which is the time when the QB throws a pass, and those of defenders who are marking the receivers; and the skill level (compatibility) of each player, we propose a new method to enable judgment that the pass to the receiver with the maximum likelihood is optimal.

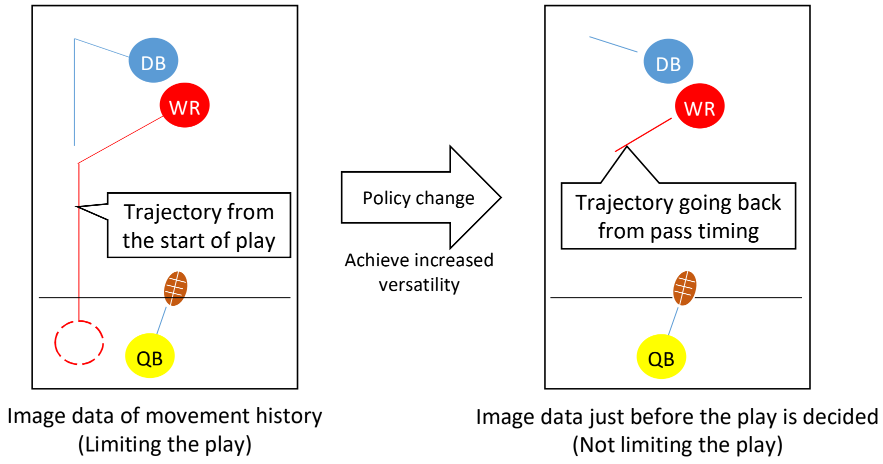


Figure 2. Policy for improving existing research

Table 1. Optimal parameters for trajectory image data

Parameter	Set value	Outline
Number of data	Adjust to the same number of cases with the smaller one	How to adjust the number of positive and negative cases in the learning data
Number of Channels	3 channels (RGB color image)	Number of channels when generating a trajectory image
With or without extension	Extend learning data by rotating and inverting	Whether learning data are extended by rotation/inversion
Drawing White Lines	No drawing	Whether lines are drawn on the field or not
line width of trajectory	4px	Line width of the athlete's movement trajectory
Drawing pass timing	Drawing	Whether points of pass timing are drawn or not
Scale of trajectory	Enlarged 1.3 times	Enlargement ratio of the trajectory image when half of field is enlarged equally.
Coloring method of trajectory	By team (regular or not) and position	Color each player's movement trajectory for indication
Image Size	32px x 32px	Size of the entire trajectory image

4. Experiments for Examining the Method of Generating Trajectories

4.1 Experiment Outline

The purpose of the experiment is to verify the hypothesis described in Section 3.3 that the success or failure of the pass play can be determined by the trajectory image that takes the account of the player's position and movement trajectory from several seconds before the time of the pass throw and the skill level of each player.

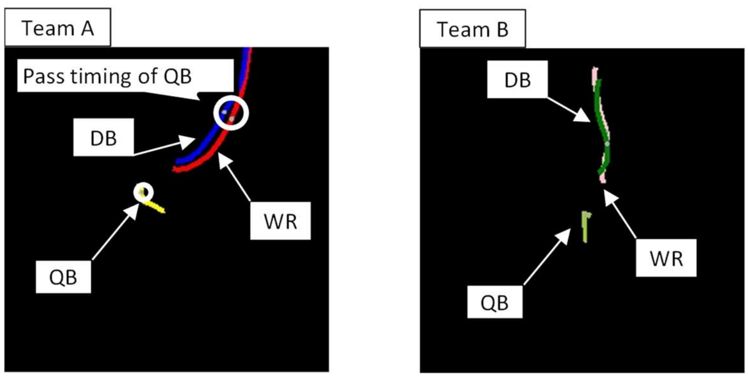


Figure 3. Example of trajectory image data

Existing researches (Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020) proposed the parameters for generation of trajectory images as shown in Table 1. It was found that the success or failure of pass can be accurately estimated by generating trajectory images (Figure 3) using the optimal set values after parametric analysis. In the trajectory images generated by this method, regular players (Team A) and semi-regular players (Team B) are distinguished by the color of their trajectories, giving meaning to the skill level of respective players simultaneously. Therefore, in this research, we also conduct experiments using trajectory images based on the knowledge above.

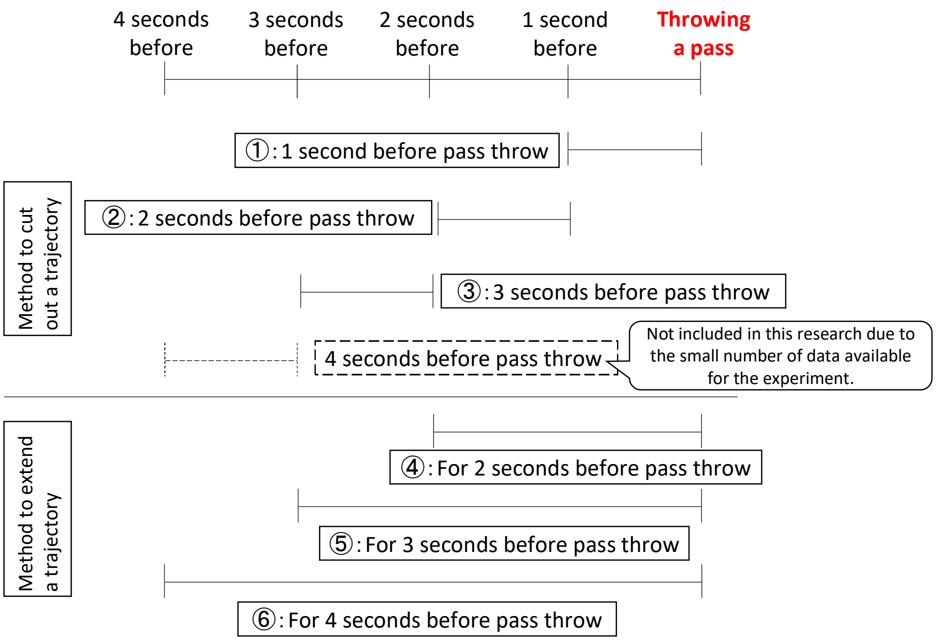
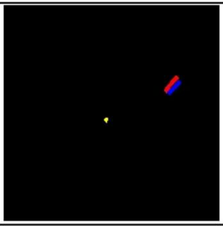
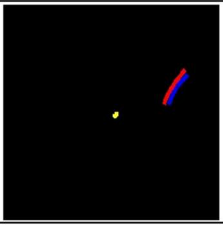
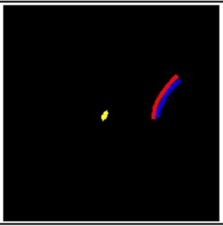
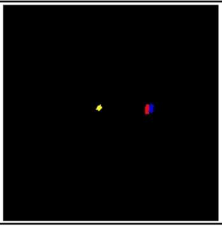
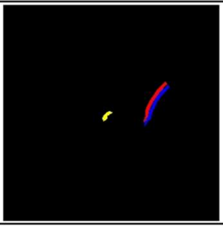


Figure 4. Generating two types of trajectory image data

As shown in Figure 4, it is considered that there are two methods of generating trajectory images that takes account of the time series with the timing of throwing pass as the origin: trajectories cut out at regular intervals (1 second in this research), and trajectories extended at regular intervals. The former (Figure 5, left) allows estimation using the characteristics of the moment of action, while the latter (Figure 5, right) allows estimation using the characteristics of changes in action. In this experiment, we verify which method is optimal using the trajectory images generated with both methods and validating the accuracy of each method. In existing researches (Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020), an F-measure of 0.600 is set as the target accuracy for determining the success or failure of a pass, as an accuracy that is in line with field experience, based on interviews with people who have experienced American football. Therefore, this research also follows this approach and sets an F-measure of 0.600 as the target accuracy.

Similar to existing research(Tanaka, C., et al. 2020), the deep learning device used in this experiment is a partially modified version of the network used in the recognition program for handwritten numeral images by TensorFlow (Figure 6). Specifically, the number of units in the input layer is set to match the size and number of channels of the generated image, and the number of units in the output layer is set to 2 units to match the success or failure of pass (2 classifications). This CNN finally outputs the likelihood of belonging to each class of success or failure of pass.

Item contents	Sample figures	Item contents	Sample figures
①1 second before pass throw (method to cut out trajectories)		④For 2 seconds before pass throw (method to extend trajectories)	
②2 seconds before pass throw (method to cut out trajectories)		⑤For 3 seconds before pass throw (method to extend trajectories)	
③3 second before pass throw (method to cut out trajectories)		⑥For 4 seconds before pass throw (method to extend trajectories)	

Legend) QB: Yellow trajectories, WR: Red trajectories, DB: Blue trajectories

Figure 5. Sample of two types of trajectory image data

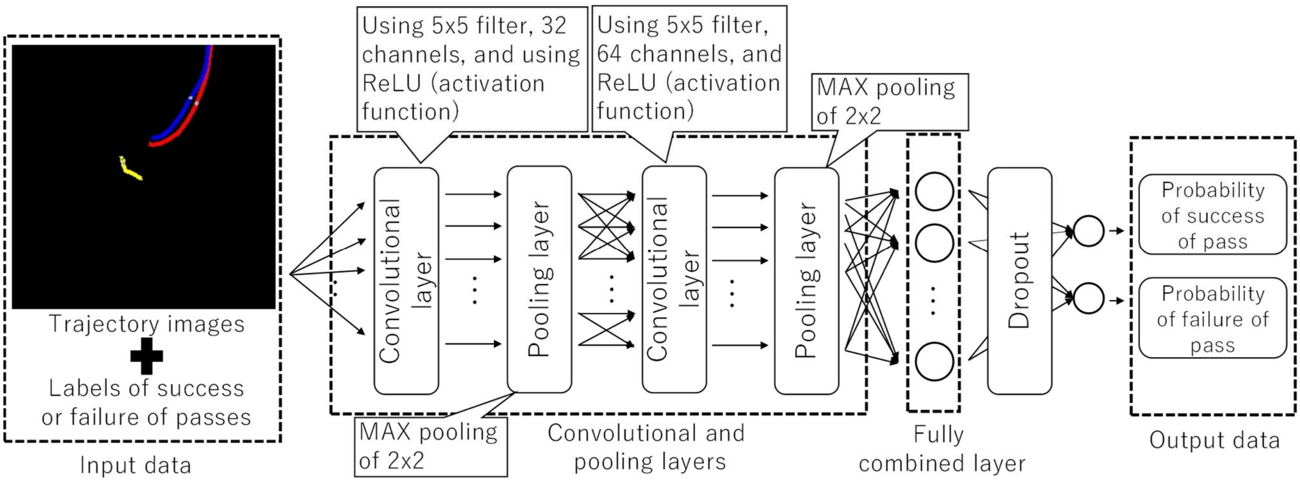


Figure 6. Network Configuration of CNN

4.2 Preparation of Experimental Data

The majority of passing plays in American football tend to be completed in approximately 3 to 4 seconds. Therefore, in this experiment, we generate trajectory images using positional information going back 1 to 4 seconds from the timing of the pass throw as its origin. The number of seconds to go back is set by taking into account the time required for the QB to receive the snap from the center of the OL and throws the ball.

The data used in this research are shown in Table 2. These data were obtained with the cooperation of the American football team of Kansai University, using GNSS sensors(4Assist, Inc., 2023) to measure practices at the Senriyama campus of Kansai University. Since the support for pass skeleton analysis in this research targets college football, it is assumed that players change every spring and fall season, unlike professional and semi-professional teams. Thus, it is required to decide the number of data according to the period of time the players can play in games and the total number of pass plays made in each game, and to make analysis with the limited amount of data.

Table 2. Number of plays for each dataset

	Learning data (cases)			Test data (cases)		
(1) 1 sec. before	Success	Failure	Total	Success	Failure	Total
(2) 2 sec. before	84	84	168	16	16	32
(3) 3 sec. before	84	84	168	16	16	32
(4) for 2 seconds	84	84	168	16	16	32
(5) for 3 seconds	84	84	168	16	16	32
(6) for 4 seconds	84	84	168	16	16	32

Since college football players can only be registered for four years and approximately 25% of the members change every year, the capability of making determination with limited number of data is also a novelty of the proposed method.

4.3 Experimental Procedure

The procedure of this experiment is shown in the following steps.

STEP1: Prepare two datasets for the two methods of cutting out trajectories and extending trajectories.
STEP2: Prepare 10 datasets for each second at random. At this point, in each dataset for each second, the learning data and the test data shall be trajectory images obtained from the same play.
STEP3: In each dataset for each second, construct a model from the training data, and make 10 trials to determine the success or failure of pass using the test data. The number of learning trials is set to 3,000, which is the number of times that existing research(Tanaka, C., et al. 2020) have shown a trend toward learning convergence.
STEP4: Calculate the success (positive example) and failure (negative example), as well as the overall precision, recall, and F-measure.
STEP5: Select one of the 10 sets with the best accuracy, then compare and verify both methods of cutting out the trajectory and extending the trajectory.

4.4 Experimental Results and Discussion

Table 3 shows the results of the method for cutting out the trajectory for every second, and Table 4 shows the results of the method for extending the trajectory. (1) through (6) of Tables 3 and 4 correspond to (1) through (6) of Fig. 5, and Table 4 (1) is the same as Table 3 (1).

The results of the method of cutting out the trajectory for every second (Table 3) shows that although the accuracy improved as the number of seconds increased from the pass timing, the F-measure of the overall results was about 0.500 (0.499). In all cases, there is a bias toward positive or negative cases. As can be seen also in Figure 5, this is probably because the trajectory in the image is short, and the color of the drawn trajectory is more strongly affected than the shape. Therefore, the method of cutting out the trajectory every second does not sufficiently capture the chronological characteristics of the trajectory, and it is considered necessary to extend the time for cutting out.

On the other hand, the results of the method of extending the trajectory (Table 4) show that the accuracy improves as the number of seconds increases, and that the F-measure (approximately 0.600), which is on the same level with to the accuracy when considering the movement history in the existing research(Tanaka, C., et al. 2020). In addition, Table 4 shows that no bias occurred in the determination results for both positive and negative cases. Therefore, it was found that the chronological characteristics of the trajectory were captured as in the existing research(Tanaka, C., et al. 2020).

Table 3. Experimental results of methods to extract trajectory: No.1 to 3

			(1)	(2)	(3)
Positive Case	Number of data		16		
	Determination result	Positive	2.1	1.8	11.9
		Negative	13.9	14.2	4.1
		Precision	0.297	0.275	0.52
		Recall	0.131	0.113	0.744
		F-measure	0.179	0.149	0.611
Negative case	Number of data		16		
	Determination result	Positive	4.6	3.9	11.1
		Negative	11.4	12.1	4.9
		Precision	0.451	0.462	0.535
		Recall	0.713	0.756	0.306
		F-measure	0.551	0.573	0.387
Overall accuracy (Average)		Precision	0.374	0.368	0.527
		Recall	0.422	0.434	0.525
		F-measure	0.365	0.361	0.499

Table 4 Experimental results of methods to extend trajectory: No.4 to 6

			(1)	(4)	(5)	(6)
Positive Case	Number of data		16			
	Determination result	Positive	2.1	8.9	9.0	9.1
		Negative	13.9	7.1	7.0	6.9
		Precision	0.297	0.525	0.543	0.61
		Recall	0.131	0.556	0.563	0.569
		F-measure	0.179	0.54	0.551	0.587
Negative case	Number of data		16			
	Determination result	Positive	4.6	8.0	7.7	5.9
		Negative	11.4	8.0	8.3	10.1
		Precision	0.451	0.532	0.539	0.593
		Recall	0.713	0.500	0.519	0.631
		F-measure	0.551	0.515	0.527	0.610
Overall accuracy (Average)		Precision	0.374	0.529	0.541	0.601
		Recall	0.422	0.528	0.541	0.600
		F-measure	0.365	0.527	0.539	0.598

From the above, it was found that it is more effective for improving accuracy to use characteristics with chronological changes than instant characteristics. Thus, we attempt to analyze tactics using a trajectory extension method in this research.

5. Verification of Versatile Analytical Support for Pass Skeletons

5.1 Experimental Outline

In Chapter 4, we tested two methods that take account of time series and confirmed the accuracy of each method. As a result, it was found that success or failure of pass can be determined while the play is in progress by generating a learning model using the method of extending the trajectory. However, the actual plays take different amounts of time depending on the movements of the QB, WR, and DB. Furthermore, the length of a play (number of seconds) varies depending on the type of pass, such as short, middle, and long passes. Consequently, the collected data may be biased by the length of each play, resulting in variations in the determination of the trajectory image. Therefore, in this experiment, we verify the usefulness of a model that has learned all the data instead of a learning model that learns every second in order to keep the learning model at constant accuracy. Then we validate the versatility of the generated learning model and discusses its applicability to tactical analysis in the real field.

5.2 Preparation of Experimental Data

In this experiment, we verify the accuracy of the learning model using all of the trajectory images extended with different number of seconds. Specifically, the model is generated by learning all data from 2 to 4 seconds before the pass which is the point of origin as shown in Table 5.

5.3 Experimental Procedure

In this experiment, we use the model that has learned the data consisting of 84 examples for each of positive and negative cases x 3 seconds (2, 3, and 4 seconds) (Table 5) used in Chapter 4 to verify the accuracy of the success or failure of the pass of the test data for each number of seconds (16 data for each). The accuracy is calculated in the same way as in section 4.3.

Table 5. Datasets of final examination

	Learning data (cases)			Test data (cases)		
	Success	Failure	Total	Success	Failure	Total
(4) 2 sec.	252	252	504	16	16	32
(5) 3 sec.				16	16	32
(6) 4 sec.				16	16	32
(4) (5) (6) All trajectories				48	48	96

Table 6. Final experimental results

			(4)	(5)	(6)	(4) (5) (6)
Positive Case	Number of data		16			48
	Determination result	Positive	11.8	11.2	9.1	32.5
		Negative	4.2	4.8	6.9	15.5
		Precision	0.596	0.736	0.666	0.667
		Recall	0.738	0.700	0.569	0.677
		F-measure	0.659	0.717	0.611	0.672
Negative case	Number of data		16			48
	Determination result	Number of Positive	8.0	4.0	4.6	16.2
		number of negative	8.0	12.0	11.4	31.8
		precision	0.656	0.716	0.624	0.673
		recall	0.500	0.750	0.713	0.663
		F-measure	0.567	0.732	0.664	0.667
Overall accuracy (Average)		precision	0.626	0.726	0.645	0.670
		Recall	0.619	0.725	0.641	0.670
		F-measure	0.613	0.725	0.638	0.670

5.4 Experimental Results and Discussion

The results of this experiment are shown in Table 6. The overall accuracy shown in Table 6 indicates that success or failure of pass can be determined more accurately than the existing research(Tanaka, C., et al. 2020) by using all of the proposed learning data. In particular, the F-measure of 0.725 was the highest in the 3 seconds from 3 seconds before the throw (5). This indicates that the trajectory at the 3 seconds before the throw has the characteristics related to the success or failure of pass most strongly. On the other hand, the accuracy decreased in the 2 seconds (4) and 4 seconds (6). This may be due to the lack of characteristics necessary for determination in the 2-second period, and to the difficulty in generating an accurate model in the 4-second period because of the small number of plays over a long period of time. Further, the columns of "(4), (5), and (6)" in Table 6 show that the accuracy for all data (from 2 sec. to 4 sec.) is 0.670, indicating that there is no variation or bias in the accuracy for the positive and negative cases, and that it is possible to determine the success or failure of pass with a certain degree of accuracy. From the above, it is considered that determination is made possible with sufficient accuracy compared with the target accuracy in the existing researches(Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020) set in this research.

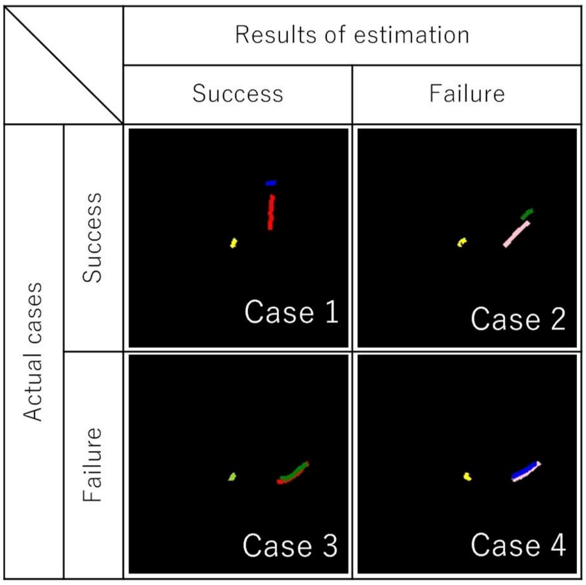


Figure 7. Cases of pass success and failure

Four cases (Figure 7) are taken from the determination results and analyzed in detail. Case 1 is a case where success was determined as success. Case 2 is a case where success was determined as failure. Case 3 is a case where failure was determined as success. Case 4 is a case where failure was determined as failure.

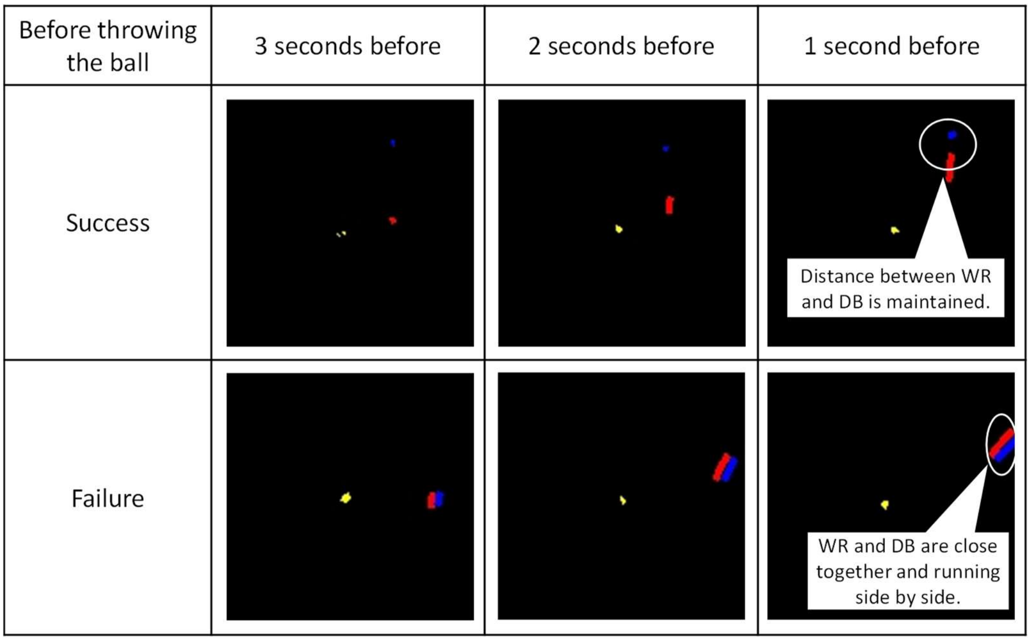


Figure 8. Characteristics of pass success and failure

First, we analyze Case 1 and Case 4, which are determined correctly. In general, the trajectories of successful and unsuccessful passes have the characteristics shown in Figure 8. For example, in the case of success, the positions of the WR (red trajectory) and the DB (blue trajectory) are far apart, and furthermore, the two players are not running alongside in view of their actions. In the case of failure, the WR and DB are positioned side by side and they have such characteristics as to run side by side all the time. The same tendency is observed in Case 1 and Case 4. In Case 1, the trajectories of the WR and the DB are apart from each other, and the WR succeeds in receiving the pass without any interference from the DB. In Case 4, the trajectories of the DB and WR overlap because the DB runs parallel to the WR in close proximity, showing a characteristic that prevents the WR from receiving the pass easily.

On the other hand, there are special cases such as Cases 2 and 3. In Case 2, as in Case 1, the WR and the DB were apart from each other, and the ball could be received. However, compared to Case 1, misdetermination occurred because the end point of the WR's trajectory and the starting point of the DB's trajectory were close. In Case 3, the WR was running along beside the DB, but overtook the DB at the end. In this case, the distance between the two players is different in comparison with Case 4. However, it is considered that misdetermination occurred because there seemed no difference in characteristics due to the number of pixels in the image.

The results of the above analysis indicate that the proposed method allowed learning the characteristics of success or failure of passes shown in Figure 8, and it was found that the method is useful for tactical analysis of pass skeletons. This means that the proposed learning data and learning method are highly practical, as success or failure of pass can be determined with no variation and with the same or higher accuracy compared with the existing research(Tanaka, C., et al. 2020) by using only the trajectory image of the point shortly before the play is decided. The proposed method is also highly versatile because it does not use information on the entire play and does not require play classification.

6. Achievement Level Check and Significance of New Insight Information

In this research, based on the needs of the managers and coaches (Table 2 in the existing research(Yamamoto, Y., et al., 2018)), we check the achievement level of the goals together with the coaches in the field. In addition, we mention the usefulness of the information gained from the achieved items that serves as new insight.

6.1 Checking Achievement Level

Table 7 summarizes the achievement level of the research results so far, including what has been realized (◎), approximately half achieved (○), and partially achieved (△).

First, what we were able to realize with the visualization system of the existing research(Yamamoto, Y., et al., 2018) are the sub-items 1, 4, 7, and 12 in Table 7. First, it has already been confirmed with the coaches that the following are made possible: 1) Grasping the distance between the players during practice or a game, 4) Confirmation of the formation as instructed, 7) Acquisition of stats information of the opponent team, and 12) Analysis of difference between regular and semi-regular players. In existing researches(Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020), it has also been demonstrated that it is possible to estimate the success or failure of passing match-up plays mainly from the information of 1) and 12), and the usefulness of this method has been evaluated. However, regarding 7), it is difficult in official matches because it is not allowed to have the opponent team wear GNSS sensors. Using the video analysis method, it is necessary to develop researches(Jiang, W., et al., 2018; Tanaka, S., et al., 2020) further to improve the accuracy of positions, recognition, and tracking of players.

Second, from the results of the passing skeleton that assumed the game format of this research, we confirmed with the coaches that 4) the formation and movements were reproduced accurately as instructed by the manager and coaches, and that 7) that the formation and movements of the opponent team during practice and practice games could also be reproduced as well. Furthermore, using all of the information from 1), 4), 7), and 12), we were able to predict the success and failure rates of passes based on the information in the 3 seconds before the QB throw in 14).

The time period of 3 seconds before throwing a pass is almost the same as the timing when the QB receives the snapped ball after the play begins, completes the drop back motion to throw the pass, determines the pass target, and throws the pass; therefore, decision making of throwing a pass at this time is very important. The instructor also gave his view that the information at this time was useful and valuable enough as a material for analytical support.

We received his opinion that in the future, when predicting the plays in item 12), he expects improvement in the prediction accuracy by taking account of the receivers' and defenders' awareness of being bad at something converted into numerical values by quantitatively evaluating the degrees of skills of the receivers, including the QB, and the trust between players not limited to regular and semi-regular players, , as well as by quantifying the stats information of the opponent team in 7). We also received a comment that in the future, it is desired to accurately obtain information of the opponent team during a game from videos taken with a video camera etc. and present support information for tactical analysis in real time.

6.2 Significance of New Insight Information

This research has been conducted for the purpose of presenting information that managers and coaches are seeking. In particular, its goal has been to contribute to improving the quality of practice by using this information. In concrete, the quantitative presentation of useful information for coaches leads to support material for formulating tactics and gaining new insight. Such information, for example, includes which plays are effective, which zones to target, which players in the own team have high ability, the compatibility between players, and the condition of players during games and practices. By applying the results of this research to pass skeleton, it will be easier for the QB to be aware of what is the timing and where to throw the ball to increase the success rate, and for the WR to be aware of what is the timing and how to run in relation to the position of defense to secure a wider area for a successful pass.

Table 7. Research achievement for leader's needs

Classification of questions	Sub-item number	Comments obtained (needs)	Level of achievement			
			Research (Yamamoto, Y., et al., 2018)	Research (Yamamoto, Y., et al., 2020).	Research (Tanaka, C., et al., 2018).	This Research
Tracking of players and the ball	1	Want to grasp the distance between players in practices and games.	◎	◎	◎	◎
	2	Want to realize highly accurate tracking of all players by integrating images taken by multiple video cameras and laser point cloud data, etc.	△	–	–	–
	3	Want to grasp the trajectory, height, number of revolutions, landing point, etc. of the ball to strengthen passing play.	△	–	–	–
Classification and Recognition of plays	4	Want to check if the formation and its movements are reproduced just as instructed by the manager and coach.	◎	○	○	◎
	5	Want to cut out one play for every few seconds from videos taken by video cameras, etc.	△	–	–	–
Formation analysis	6	Want to grasp the formation and its movements in real time without attaching equipment to the players.	△	–	–	–
	7	Want to obtain the formation and stats information of the opponent team in real time.	◎	–	–	–
Players' performance evaluation	8	Want to know the fatigue status in order to make a decision to replace a player.	△	–	–	–
	9	Want to know steps, training intensity, play bias, and sight movement.	△	–	–	–
	10	Want to know to what degree players are performing during practice or games by measuring their top speed and maximum heart rate in usual time.	△	–	–	–
	11	Want to grasp the duration of the player's top speed.	△	–	–	–
	12	Want to know the compatibility between players in pass play.	◎	◎	◎	◎
	13	Want to know to what degree players are impacted to prevent injury.	△	–	–	–
	14	Want to predict the success rate of a play when it has become possible to obtain the formation and its movement of players of both of own and opponent team.	△	○	○	◎

"△" indicates items that can be confirmed by the visualization system if measurement data is available.

"-" indicates items that need further examination by introducing other devices, including video cameras.

In addition, even the excellent coaches are unsure about the next play call. It is because the situation of each player and the game situation (Table 2 in the existing research(Yamamoto, Y., et al., 2020)) are not always the same, and accordingly, decisions tend to be based on experience and intuition rather than logical thinking. Consequently, if the future can be predicted from past data regarding the rights and wrongs about the selection of the subsequent play and its success or failure, the current problem can be solved. It can be considered that in the future, it will be possible to select appropriate plays with a high degree of accuracy by collecting players' positional information in real time and storing it in the learning device.

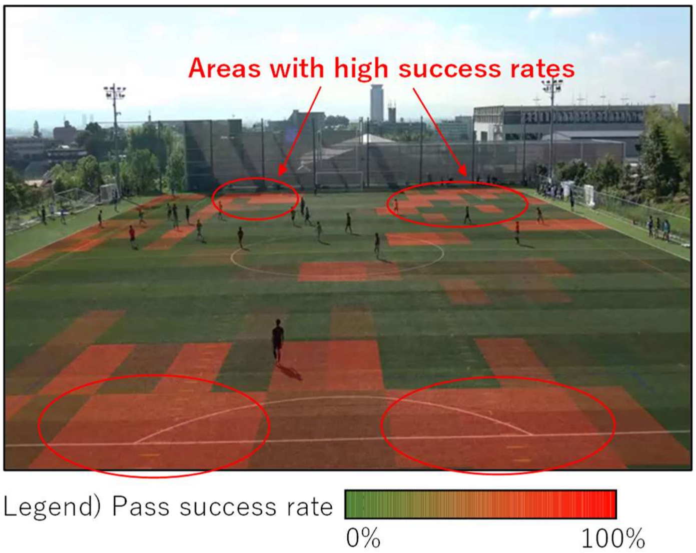


Figure 9. Heat map of pass success rate

From the above, we were able to reconfirm the significance and importance of the newly perceived insightful information together with managers and coaches. We believe that the advancement of sports information processing will allow the level to improve from qualitative understanding of meaning to quantitative one for those who play, watch, support, and entrust sports, and consequently that sports will transform from an "unplotted drama" with contingency into a "predictable drama" with necessity in the near future.

7. Future Outlook

There are roughly four parts we plan to develop in the future.

For the first part, we will extend the maximum likelihood in order to connect to the first down and touchdowns. In the pass skeleton, when we created a CNN success/failure determination device using the trajectory images of OF and DF, we obtained a determination rate of over 70% using the determination device in which the trajectory images from 3 seconds before throwing the pass were input. As a result, for each play in the pass skeleton, the success rate of the pass was estimated using this determination device for the assumed player to receive the pass, enabling determination that the pass to the receiver with the maximum likelihood was optimal. However, since we have given the highest priority to visualization of trajectory images for the coaches, which has been the research policy so far, we have been adopting CNN. Although CNN is good at analyzing fixed-length data, the amount of data increased due to the need to work out in order to take time into account. While it is possible in this method to predict success or failure based on the distance between players, the skill of each player, and the skill levels (compatibility) between players, it is difficult to predict the maximization of results such as where the receiver receives the pass while considering the speed of the receiver, and how far the receiver can advance after receiving the pass while maintaining his speed and breaking away from the defenders. Thus, using Recurrent NN, which is advantageous in being variable so that it can take account of time, and simple because of dealing with only position coordinates, we are planning to confirm that this brings about the results as good as or better than the results obtained using information from 3 seconds before the QB's passing time as the point of origin, then consider the information quantified for improving the prediction accuracy in 6.1 Section, and finally examine the maximum likelihood of the results in depth.

For the 2nd part, we will conduct a piece of research for supporting the analysis of scrimmages for game-style pass plays and for all plays to be assumed including run plays. At the same time, we plan to examine the use of image processing to obtain ball tracking information.

For the third part, we will progress a piece of research on the analysis method using video images in parallel, and also examine real-time data in depth. Moreover, we plan to obtain other kind of information that managers and coaches want to know by using new sensor devices in combination. For example, we are planning to use a biometric sensor to obtain heart rate and fatigue level etc., and to use image processing together with the biometric sensor to obtain the number of steps taken by the athlete as well as training intensity and so on.

Furthermore, for the fourth part, also in other field sports, we research application to plays in which the ball is passed, such as soccer, track and field hockey, and lacrosse. These require the player to maintain continuity while passing to an open space with eye contact. In particular, more passes of good quality will lead to a goal(Power, P., et al., 2017). Therefore, in any given situation, creation of a heat map to show the zones(Figure 9) where pass success or failure probability is high based on the information about the position and movement trajectory of all players for several seconds before the pass will lead to an improvement in the ball retention rate(Jiang, W., et al., 2019) and provide useful information that the coaches seek.

These four parts will be pursued in future researches.

8. Conclusion

The authors have been examining whether it is possible to determine success or failure of pass matchups(Yamamoto, Y., et al., 2020; Tanaka, C., et al. 2020) by applying CNN to trajectory image data of American football pass plays. The idea, which is the starting point for these researches, was that there was a need to accurately visualize whether the players are accurately taking the right course of the play. Then, it was necessary to confirm the information on the completion of the play and to judge whether the play was good or bad. However, it is very difficult even for managers and coaches to determine whether a play is good or bad.

Thus, regarding prediction of success or failure of passes in the pass skeleton that has conventionally required consideration of diverse parameters such as the positions and movements of respective players from the point of starting the play to the success or failure of the pass, as well as the skill level (compatibility) of the players, we have conducted this research on the assumption that it is possible to determine success or failure by focusing on the movement trajectory of the receivers and the defenders marking them from several seconds before the time when QB throws the pass as the point of origin. Then, we have created a deep learning device for success/failure determination using the information about the trajectories and the positions of passes of the QB, receivers and defenders, as well as information on the skill level of the players (regular or semi-regular) in which the compatibility between the players is inherent. As a result, we have obtained the determination rate that exceeds 70% using the determination device into which the trajectories from 3 seconds before throwing a pass are input. Consequently, we have confirmed that useful information can be provided to support strategical planning during games or coaching during practice, since this determination device allows prediction of the success or failure rate of pass to the assumed passer for each play in the pass skeleton, indicating that the pass to the receiver with the highest likelihood is determined as optimal. Such prediction results can be used for feedback after the match and for planning tactics using intercom during the match. On the other hand, the accuracy of the prediction results depends on the training data, so high accuracy can be achieved when using data from one's own team, and accuracy will decrease when using data from other teams.

From the above, this research has shown new knowledge and views in the area of information processing in sports. In addition, this research is expected to contribute to the application or development of new technologies such as judgment of the use of players at the critical point of a game, by not only visualizing players' movements but also giving quantified numerical information including the estimation results of success or failure of passes that take the skill level (compatibility) of the players into account. This information is expected to contribute to the application and development of new technologies, such as decisions on the use of players at the critical point of a game. At the same time, we have obtained results that contribute to practical "Sports x ICT" for solving advanced problems in the real world.

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Author Contributions

Conceptualization, S.T., I.H. and S.N.; methodology, Y.Y. and K.N.; software, W.J. and C.T.; validation, W.J. and C.T.; formal analysis, Y.Y., K.N., W.J. and C.T.; investigation, W.J. and C.T.; resources, S.T., I.H. and S.N.; data curation, W.J. and C.T.; writing—original draft preparation, W.J. and C.T.; writing—review and editing, S.T., K.N., I.H., S.N., Y.Y. and W.J.; supervision, S.T., I.H. and S.N.; project administration, S.T., I.H. and S.N.; funding acquisition, S.T., I.H. and S.N.

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Conflicts of Interest

The authors declare no conflict of interest.

References

4Assist, Inc.(2023). GPS System SPI HPU, http://4assist.co.jp/gpsports/gpsports_top2.html.

Arumugam, D., Sibley, M., Griffin, J., Stancil, D. and Rickeets, D.(2013). An Active Position Sensing Tag for Sports Visualization in American Football. *International Conference on RFID*, 96-103.

Atmosukarto, I., Ghanem, B., Ahuja, S., Muthuswamy, K. and Ahuja, N.(2013). Automatic Recognition of Offensive Team Formation in America Football Plays, *Conference on Computer Vision and Pattern Recognition Workshops*, 991-998.

Beckwith, G., Callahan, T., Carlson, B., Fondren, T., Harris, R., Hoege, J., Martin, T., Menna, C., Summer, E., Scherer, W., Tuttle, C. and Adams, S.(2019). Systems Analysis for University of Virginia Football Recruiting and Performance, *Systems and Information Engineering Design Symposium*, 1-6.

Bruke, B.(2019). DeepQB: Deep Learning with Player Tracking to Quantify Quarterback Decision-Making & Performance, *MIT Sloan Sports Analytics Conference*.

Catapult(2023). Find Your Football Fingerprints, http://www.catapultsports.com/sports/football/.

Chen, C., Lai, W., Hsieh, H., Zheng, W., Wang, Y. and Chuang, J.(2018). Generating Defensive Plays in Basketball Games, *MM '18, Proceedings of the 26th ACM international conference on Multimedia*, 1580-1588.

Chen, S., Feng, Z., Lu, Q., Mahasseni, B., Fiez, T., Fern, A. and Todorovic, S.(2014). Play Type Recognition in Real-World Football Video, *Winter Conference on Applications of Computer Vision*, 652-659.

Chen, S., Fern, A. and Todorovic, S.(2015). Person Count Localization in Videos from Noisy Foreground and Detections, *Conference on Computer Vision and Pattern Recognition*, 1364-1372.

Dutta, R., Yurko, R. and Ventura, S.(2020). Unsupervised Methods for Identifying Pass Coverage Among Defensive Backs with NFL Player Tracking Data, *Journal of Quantitative Analysis in Sports*, 143-161.

Hayashi, M., Yamamoto, T., Aoki, Y., Ohshima, K. and Tanabiki, M.(2013). Head and Upper Body Pose Estimation in Team Sport Videos, *2nd IAPR Asian Conference on Pattern Recognition*, 754-759.

Hudl(2025). hudl Japan Official Website, https://jp.hudl.com/ja.

Intille, S. and Bobick, A.(1999). A Framework for Recognizing Multi-agent Action from Visual Evidence. *Proceedings of the National Conference on Artificial Intelligence*, 518-525.

Jiang, W., Yamamoto, Y., Nakamura, K., Tanaka, S., Tanaka, C., Masaki, H., Yamada, T., Fujimoto, Y. and Naruo, T.(2019). Research and Development of Coach Oriented Visualization System for Field Sports, *IPSJ Journal*, *60*(5), 1212-1227.

Jiang, W., Yamamoto, Y., Tanaka, S., Nakamura, K. and Tanaka, C.(2018). Research for Identification and Positional Analysis of American Football Players Using Multi-Cameras from Single Viewpoint, *Journal of Japan Society of Photogrammetry and Remote Sensing*, *57*(5), 198-216.

Kurano, J., Hayashi, M., Yamamoto, T., Oshima, K., Tanabiki, M. and AOKI, Y.(2015). Ball Tracking in American Football Video Using Information of Play Initial and Terminal Points and Each Player's Movement, *Journal of the Japan Society for Precision Engineering*, *81*(1), 91-98.

Kurano, J., Yamamoto, T., Hayashi, M., Kataoka, H. and Aoki, Y.(2013). Creation of Pass Success Probability Map for Sports Video Analysis, *ITE Technical Report*, *37*(36), 45-48.

Laviers, K. and Sukthankar, G.(2014). Using Opponent Modeling to Adapt Team Play in American Football, *Plan, Activity, and Intent Recognition*, pp. 313-341.

Lee, N. and Kitani, K.(2016). Predicting Wide Receiver Trajectories in American Football, *Winter Conference on Applications of Computer Vision*, 1-9.

Li, R. and Chellappa, R.(2010). Recognizing Offensive Strategies from Football Videos, *International Conference on Image Processing*, 4585-4588.

Ministry of Education, Culture, Sports, Science and Technology(2023a). Establishment of Sports Agency and Promotion of Sports Policy, https://www.mext.go.jp/sports/b_menu/soshiki2/1373916.htm.

Ministry of Education, Culture, Sports, Science and Technology(2023b). Japan Sports Agency, http://www.mext.go.jp/sports/.

Molineaux, M., Aha, D. and Sukthankar, G.(2009). Beating the defense: Using Plan Recognition to Inform Learning Agents. *Proceeding of the Twenty-Second International Florida Artificial Intelligence Research Society Conference*, 337-343.

Power, P., Ruiz, H., Wei, X. and Lucey, P.(2017). Not All Passes Are Created Equal: Objectively Measuring the Risk and Reward of Passes in Soccer from Tracking Data, *International Conference on Knowledge Discovery and Data Mining*, 1605-1613.

Swears, E. and Hoogs, A.(2012). Learning and Recognizing Complex Multi-agent Activities with Applications to American Football Plays, *Workshop on the Applications of Computer Vision*, 409-416.

Takayanagi, R., Malla, D., Sakai, T. and Sogabe, T.(2020). Research on American Football Coaching Strategy Using Deep Reinforcement Learning, *Annual Conference of the Japanese Society for Artificial Intelligence*, *34.*

Tanaka, C., Yamamoto, Y., Jiang, W., Tanaka, S., Hayashi, I., Nakamura, K. and Nakajima, S.(2022a). Research for Supporting Tactical Analysis Concerning Pass Skeleton in American Football -Demonstration Experiment-, *Image Laboratory*, *33*(4), 24-34.

Tanaka, C., Yamamoto, Y., Jiang, W., Tanaka, S., Hayashi, I., Nakamura, K. and Nakajima, S.(2022b). Research for Supporting Tactical Analysis Concerning Pass Skeleton in American Football -Survey and Proposal-, *Image Laboratory*, *33*(3), 27-34.

Tanaka, C., Yamamoto, Y., Jiang, W., Tanaka, S., Nakamura, K. and Nakajima, S.(2020). Research for Pass Matchup Analysis Considering Movement Records in American Football, *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics*, *32*(1), 580-589.

Tanaka, S., Yamamoto, Y., Jiang, W., Nakamura, K., Seio N. and Tanaka, C.(2020). Research for Tracking Athletes Using Images Shot from Multiple Points of View, *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics*, *32*(4), 821-830.

Tani, T., Huang, H., and Kawagoe, K.(2014). Visualization System for Play Strategy Decision Support Using Trajectory Mining, *The 6th Forum on Data Engineering and Information Management*, E1-6.

Varadarajan, J., Atmosukarto, I., Ahuja, S., Ghanem, B. and Ahuja, N.(2013). A Topic Model Approach to Represent and Classify American Football Plays, *British Machine Vision Conference,* 64.1-64.12.

Yamamoto, Y., Tanaka, S., Jiang, W., Nakamura, K., Tanaka, C. and Seio, N.(2018). Development of Visualization System and Positional Play Analysis for American Football, *IPSJ Journal*, *59*(5), 1334-1350.

Yamamoto, Y., Tanaka, S., Nakamura, K., Tanaka, C., Jiang, W. and Hayashi, I.(2020). Research for Matchup Analysis of Pass Play in American Football with Deep Learning, *Journal of Japan Society for Fuzzy Theory and Intelligent Informatics*, *32*(1), 590-603.