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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.

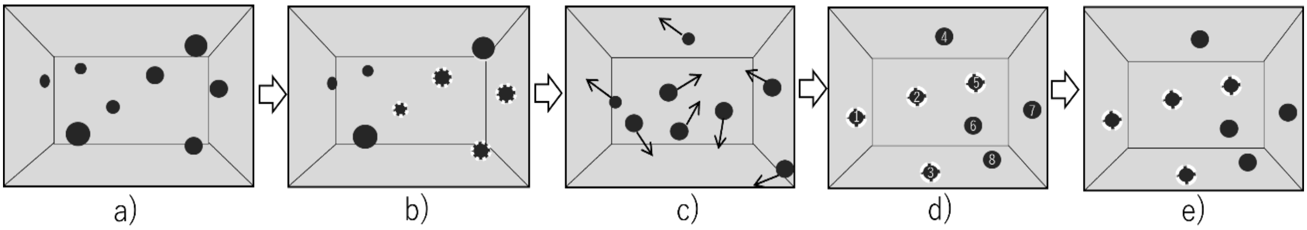

Figure 1. Detailed protocol for NT tasks.

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

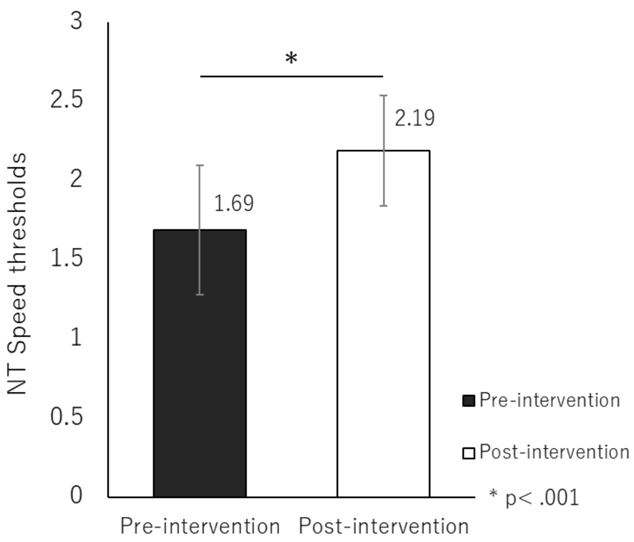

Figure 2. Changes in MOT skills before and after NT training.

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.

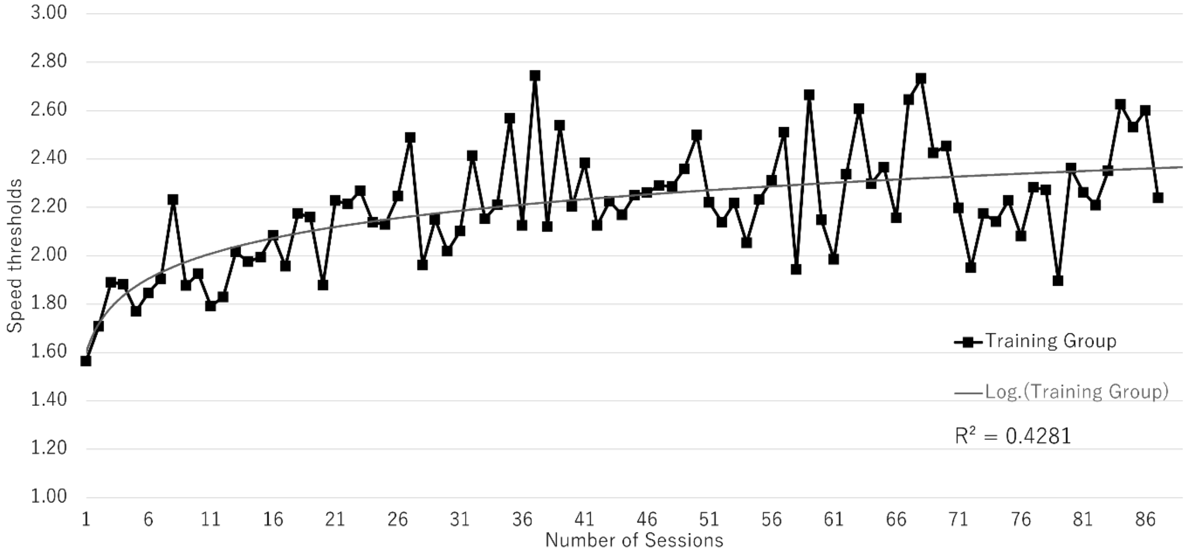

Figure 3. Geometric means of professional baseball players in relation to NT training sessions.

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, $M = 82.17 \pm 27.05$ and post-intervention, $M = 129.33 \pm 9.60$. 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.

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