

Differences in brain activity during motor imagery of shotput between the whole- and part-training methods

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ABSTRACT

We compared the differences between the brain regions activated during motor imagery using the whole-training and part-training methods and focused on how brain-activation patterns vary depending on athletes' individual characteristics. We included four throwing athletes with varying levels of competitive ability and shotput specialization, including elite athletes who attained upper ranks in the Japan Championships. The experimental tasks included motor imagery of a complete shotput attempt (whole method) and standing throw excluding the glide phase (part method). Functional magnetic resonance imaging was used to measure brain activity during these tasks. The results showed that individual variations in the brain regions were activated by both the whole and part methods. Regarding the inter-individual differences between the whole and part methods, in one high-level athlete, more brain regions, including the frontal lobe, were activated in the whole method compared to the part method. For athletes with lower competitive levels or specialization, no significant difference in brain activity was observed between the motor imagery of the whole and part methods. Thus, there are inter-individual differences in the brain regions that are activated during whole- and part-training methods and these vary depending on the athletes' competitive ability and specialization.

Keywords: Performance analysis, Glide, Whole method, Part method, fMRI.

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INTRODUCTION

In sports training, motor learning constitutes a fundamental concept in the development of performance-related skills. Within the framework of motor learning, two instructional methods – the whole method and the part method (Swanson & Law, 1993) – are widely employed. The whole method involves practicing an entire motor task from start to finish, whereas the part method breaks the task into smaller segments that are initially practiced separately before being combined (Echigo & Iwatsuki, 2017). Despite the merits of both methods, the selection of the optimal approach in applied-training settings requires careful consideration of each method's characteristics, the athlete's skill level, and the training volume or sequence. Although the part method may yield greater motor-learning effects when critical task components are isolated and emphasized (Yoneda & Suzuki, 2014), in some cases, re-integrating part-practice training into the whole method effectively enhanced performance (Sugihara, 2003). The part method is particularly effective during the early stages of motor learning (Yamamoto, 1985). However, the effectiveness of each method can vary depending on individual characteristics, such as an athlete's performance level and domain-specific expertise. Thus, when assessing the most suitable motor learning method, both the training frequency (an indicator of expertise) and performance level must be considered to account for the differences among individual learners.

To better understand the relationship and effectiveness of the whole and part methods and to incorporate the differences in individual characteristics, a better approach to training optimization may be proposed. One such method is functional magnetic resonance imaging (fMRI), which enables the observation of motor-learning associated brain-activity patterns. fMRI-based examination of changes in brain activation during the learning of new motor skills (Karni et al., 1998) has facilitated the inference of mechanisms whereby different brain regions contribute to skill acquisition. However, because fMRI is highly sensitive to head motion, most studies have relied on simple limb movements as experimental tasks rather than on high-velocity full-body sports movements, such as jumping or throwing. This technical limitation makes it impractical to record real-time neural activity during complex athletic movements, such as shotput. As an alternative, researchers have widely employed motor imagery—which involves the mental simulation of movement without physical execution—as a proxy to investigate neural mechanisms in sports such as gymnastics, basketball, and volleyball (Wei & Luo, 2010; Mizuguchi et al., 2016; Zhang et al., 2019). When performed repetitively, motor imagery facilitates motor learning in a manner that is comparable to that of physical training (Pascual-Leone et al., 1995). This effect is explained by the overlap in brain regions recruited during both actual movement and motor imagery, particularly in motor-related cortical areas (Lotze & Halsband, 2006). As motor imagery activates nearly the same neural circuitry as physical movement, it is considered a valid approach for inferring motor-related brain activity in the absence of overt motion. Therefore, fMRI-based analysis of the differences in brain activity between whole- and part-method imagery can reveal the differences in the recruited neural circuits that are during each method, which would provide a neural basis for evaluating the effectiveness, efficiency, and appropriateness of each method. Furthermore, brain-activation patterns during motor imagery depend on expertise and competition levels. For example, Olsson et al. (2008) demonstrated that experienced high jumpers activated motor-related areas during imagery, whereas nonathletes did not. This implies that the internal motor representation of a task is more sophisticated in well-trained athletes. Therefore, we proposed the following three hypotheses for shotput as the research model:

1. Athletes with high expertise and competitive ability will show greater neural recruitment during whole-method imagery, and that reflects the presence of a well-developed internal motor representation for the glide technique.

2. Athletes with low competitive ability but high expertise may not yet have integrated the glide technique into a coherent motor program. Thus, the part-method imagery is expected to elicit greater activation owing to familiarity with individual task elements.
3. Athletes with high performance but low specialization (i.e., those who excel in another event) will show limited neural activation during both whole and part imagery, owing to the lack of refined motor representation for shotput-specific movements.

This study aimed to investigate the brain regions recruited during motor imagery of the whole and part methods in shotput, and to examine interindividual differences in these patterns.

METHODS

Participants

To explore neural differences in motor imagery and their relationship with expertise and performance levels, this case study used fMRI data from four collegiate athletes, with varying profiles, from a university track and field team that specializes in throwing events participated in this study. All participants had prior competitive experience using the glide technique in official shot-put events and had undergone training using both the whole method (full glide motion) and the part method (standing throw). Ethical approval was obtained from the Human Research Ethics Committee of AAA University (Approval No. 2019-084).

- Participant A: The main event was a hammer throw (the national champion). Shotput was a secondary event with competition-level performance but low training frequency (training began only approximately 10 days before the competition). He was characterized by a highly competitive ability but low specialization in shotput.
- Participant B: Shotput was the primary event, with competition performance at the national level. This athlete has a highly competitive level and specialization.
- Participants C and D: Shotput was the primary event. The performance records and IAAF scores of the athletes indicated comparable abilities, with both competing at the intercollegiate championship level. They exhibited high specialization but a relatively lower competitive level.

The detailed participant profiles are shown in Table 1. All four athletes were nationally ranked within the top 100 on the official shotput-ranking website maintained by Baseball Magazine Co., which includes approximately 1,000 registered competitors. Therefore, all the participants were considered elite athletes, although their competitive levels differed intentionally. In addition to their personal best records (PB) and seasonal best records (SB), the IAAF scoring metrics were used to allow enable a sex-neutral comparison of performance levels.

Table 1. Participant information.

	Gender	Dominant hand	Event	PB (m)	SB (m)	IAAF score	Competition history (years)	Age (years)
Participant A	M	R	Second	17m41	17m41	967	7	21
Participant B	F	R	Main	15m75	15m40	943	8	21
Participant C	M	L	Main	15m10	15m03	830	8	20
Participant D	M	R	Main	15m08	14m97	829	7	20

Target motor task

This study focused on shotput, track, and field events wherein the objective was to throw as heavy an implement as possible. The total throwing distance consisted of the distance covered before and after

release, with the majority of the distance resulting from the post-release projectile motion. The key biomechanical determinants of this distance include the release height, angle, speed, and air resistance, with the release speed playing a particularly critical role (Hay, 1993). The release speed, typically referred to as the initial velocity, is primarily generated by the acceleration of the shot during the delivery phase. According to Tauchi et al. (2006), in the glide technique, the most crucial phase for generating acceleration commenced from the moment the lead leg contacted the ground and extended to the point of release (the left leg for right-handed athletes and vice versa). This segment, often referred to as the delivery phase, is fundamental in determining the performance. One training method specifically designed to target the delivery phase is the standing throw, which isolates and reproduces this segment of the shot-put motion (Altmeyer et al., 1994). From a motor learning perspective, the standing throw fits the definition of the part method, as it isolates and practices a sub-component of the full skill (Echigo & Iwatsuki, 2017). Thus, in this study, the standing throw was designated as a representative task for the part method. In contrast, the whole method entails executing and repeating the entire sequence of a motor task from beginning to end (Echigo & Iwatsuki, 2017). Accordingly, the full-glide shotput motion, from the starting stance through the glide and culminating in the follow-through, was designated as the whole-method task in this study.

MRI Measurements

Functional magnetic resonance imaging of the brain was performed using a 3-Tesla MRI scanner (SIGNA Premier, GE) equipped with a 48-channel head coil. The imaging parameters were as follows: repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, field of view (FOV) = 212 mm × 212 mm, flip angle = 80°, matrix size = 64 × 64, slice thickness = 3.2 mm, interslice gap = 0.8 mm, and the number of volumes per run = 144.

Experimental protocol

Two types of motor imagery tasks were used:

1. Whole method: Imagery of the full-glide shotput sequence, including the delivery phase.
2. Part method: Imagery of the standing throw, which isolates the delivery phase.

To avoid influencing the participants' natural imagery strategies, no explicit instructions were provided regarding the perspective (first or third person) or sensory modality (kinaesthetic vs. visual). This approach facilitated the exploration of individual imagery tendencies without introducing a cognitive bias.

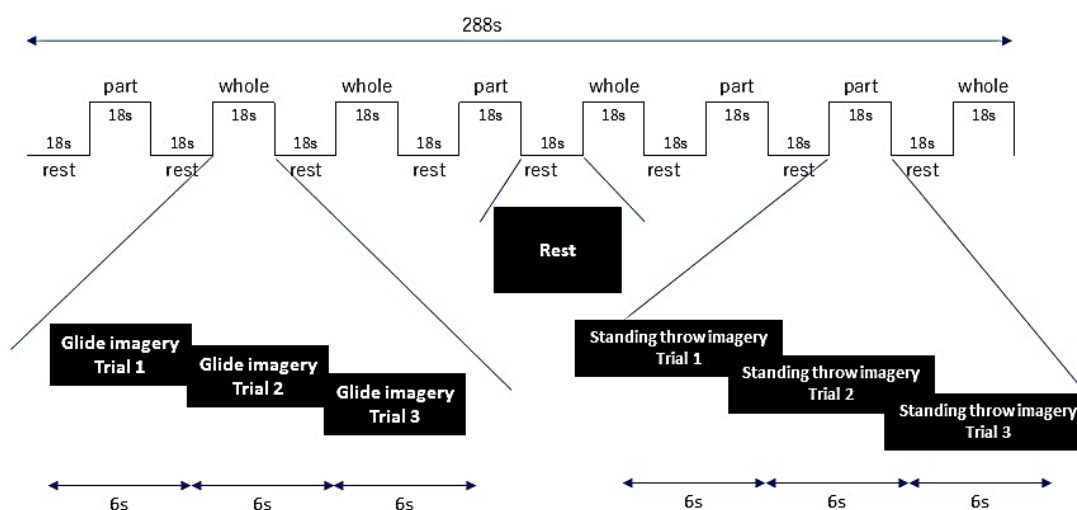


Figure 1. fMRI measurement experiment protocol.

During fMRI scanning, the participants were instructed to remain at rest before and after each imagery task. Task cues were displayed on a monitor positioned beside the scanner, and participants lying in the supine position viewed the monitor through a mirror mounted on a head coil. Each imagery trial was standardized as follows: one motor imagery attempt lasted 6 seconds, beginning with entering the shotput circle and assuming the starting posture. Each task block consisted of three consecutive imagery repetitions for 18 s. This was followed by an 18 seconds rest block. One full set consisted of the following sequence = Whole method → rest → Part method → rest. The total time per set was 72 s. Each participant completed four full sets, resulting in a total scan time of 288 s (4×72 s). The experimental protocol is illustrated in Figure 1.

After the MRI session, participants completed a qualitative questionnaire to report their introspective experiences during imagery. The questionnaire consisted of two open-ended items.

1. Perception of Whole vs. Part practice (e.g., which was easier or more effective).
2. Description of how each motor imagery task was executed mentally.

Furthermore, imagery tendencies were evaluated using the Japanese version of the Movement Imagery Questionnaire-Revised (JMIQ-R) (Hasegawa, 2004). The JMIQ-R consists of four items on kinaesthetic imagery (items 1, 3, 5, and 7) and four items on visual imagery (items 2, 4, 6, and 8). Participants rated each item on a 7-point Likert scale (1 = very difficult, 7 = very easy). Kinaesthetic imagery refers to bodily or proprioceptive sensations, whereas visual imagery refers to externally observed movements.

Data analysis

Preprocessing and statistical analyses of the acquired neuroimaging data were conducted using Statistical Parametric Mapping 12 (SPM12) in MATLAB (MathWorks, Inc.). The preprocessing pipeline included the following steps, which were performed as a batch process: (1) realignment of functional images to correct for head motion across time series, (2) slice timing correction to adjust for differences in acquisition time between slices, (3) co-registration of functional images to the corresponding structural images, (4) normalization to transform individual brains into a standard anatomical space, and (5) spatial smoothing using a Gaussian kernel with a full width at half maximum (FWHM) of 8 mm to reduce high-frequency spatial noise. Following preprocessing, the blood-oxygen-level-dependent (BOLD) time-series data were analysed using a general linear model (GLM). Neural activity associated with task performance was estimated based on parameter values that minimized the residuals in the model fit. For each participant, four types of statistical contrasts were computed: (a) brain regions activated during the whole imagery task compared to rest (whole imagery > rest); (b) brain regions activated during the part imagery task compared to rest (part imagery > rest); (c) regions showing greater activation during whole imagery than during part imagery (whole imagery > part imagery); and (d) regions showing greater activation during part imagery than during whole imagery (part imagery > whole imagery). Statistical inference was performed using family wise error (FWE) correction at the cluster level, with a significance threshold of $p < .05$, and a minimum cluster size of 10 voxels.

RESULTS

Brain activation during motor imagery for each participant

Figures 2–5 illustrate the brain activity observed in each participant, and these depict the following contrasts: (a) brain regions showing significantly greater activation during whole-method imagery than during rest; (b) brain regions showing significantly greater activation during part-method imagery than during rest; (c) brain regions showing significantly greater activation during whole-method imagery than during part-method imagery; and (d) brain regions showing significantly greater activation during part-method imagery than during whole-method imagery.

Table 2. Brain activity area when imagining the whole study method and the part study method for each participant.

Participant A Whole						Participant A Part							
Hemisphere	Cluster	Size (voxels)	MNI coordinate				Hemisphere	Cluster	Size (voxels)	MNI coordinate			
			X	Y	Z	BA				X	Y	Z	BA
R		234	40	-4	60	6			n.s.				
L		22	-4	2	56	6							
L		11	-42	30	38	8							
R		36	40	44	22	10							
R		14	54	8	18	44							
L		16	-52	8	14	44							
Participant B Whole						Participant B Part							
Hemisphere	Cluster	Size (voxels)	MNI coordinate				Hemisphere	Cluster	Size (voxels)	MNI coordinate			
			X	Y	Z	BA				X	Y	Z	BA
L		1775	-44	-2	50	6	R		1786	52	2	44	6
R		2603	40	46	22	10	L		906	-56	8	40	6
L		2687	-44	-54	12	39	L		1451	-2	-6	58	6
R		2396	66	-38	28	40	R		623	40	46	26	9
R		8922	48	16	-6	47	R		308	70	-24	20	40
Participant C Whole						Participant C Part							
Hemisphere	Cluster	Size (voxels)	MNI coordinate				Hemisphere	Cluster	Size (voxels)	MNI coordinate			
			X	Y	Z	BA				X	Y	Z	BA
L		5075	-44	-4	48	6	L		4671	-42	-4	48	6
L		726	-34	42	26	9	L		1115	-34	42	26	9
R		85	34	44	18	10	R		213	32	42	18	10
L		327	-46	-62	0	37	L		1104	-30	22	6	13
L		1866	-60	-24	32	40	L		1095	-10	-80	-2	18
L		948	-52	4	10	44	L		1547	-52	-40	30	40
Participant D Whole						Participant D Part							
Hemisphere	Cluster	Size (voxels)	MNI coordinate				Hemisphere	Cluster	Size (voxels)	MNI coordinate			
			X	Y	Z	BA				X	Y	Z	BA
R		323	36	50	30	9	R		486	2	26	42	8
L		784	-26	52	20	10	R		505	36	50	28	9
L		785	-42	12	0	13	L		696	-26	52	20	10
L		4365	-6	-102	8	18	L		3397	-6	-100	8	18
R		978	68	-26	28	40	R		813	68	-26	26	40
R		743	52	22	4	45	L		589	-54	-42	24	40

Table 3. Differences in brain activity areas between whole study method and part study method.

Participant A Whole-Part						Participant A Part-Whole					
Hemisphere	Cluster Size (voxels)	MNI coordinate				Hemisphere	Cluster Size (voxels)	MNI coordinate			
		X	Y	Z	BA			X	Y	Z	BA
n.s.						n.s.					
Participant B Whole-Part						Participant B Part-Whole					
Hemisphere	Cluster Size (voxels)	MNI coordinate				Hemisphere	Cluster Size (voxels)	MNI coordinate			
		X	Y	Z	BA			X	Y	Z	BA
R	73	18	66	18	10	n.s.					
R	10	8	72	-8	10						
Participant C Whole-Part						Participant C Part-Whole					
Hemisphere	Cluster Size (voxels)	MNI coordinate				Hemisphere	Cluster Size (voxels)	MNI coordinate			
		X	Y	Z	BA			X	Y	Z	BA
n.s.						n.s.					
Participant D Whole-Part						Participant D Part-Whole					
Hemisphere	Cluster Size (voxels)	MNI coordinate				Hemisphere	Cluster Size (voxels)	MNI coordinate			
		X	Y	Z	BA			X	Y	Z	BA
n.s.						n.s.					

Tables 2 and 3 list the statistically significant brain regions for each participant under each contrast condition, including the corresponding Brodmann areas (BA), peak MNI coordinates, and cluster sizes. Figures 2–5 overlay these activation patterns onto a standard brain template for visualization. The following is a summary of the results for each participant.

Participant A

During whole-method imagery, Participant A exhibited significantly greater activation than the other participants in the following regions: the bilateral premotor cortex, bilateral supplementary motor area (SMA), left frontal eye field, right dorsolateral prefrontal cortex (DLPFC) in the frontal pole, and the bilateral inferior frontal gyrus (pars opercularis). In contrast, the part-method imagery did not elicit significant activation compared to the resting condition. No significant differences were observed between the two imagery tasks (i.e., whole > part or part > whole).

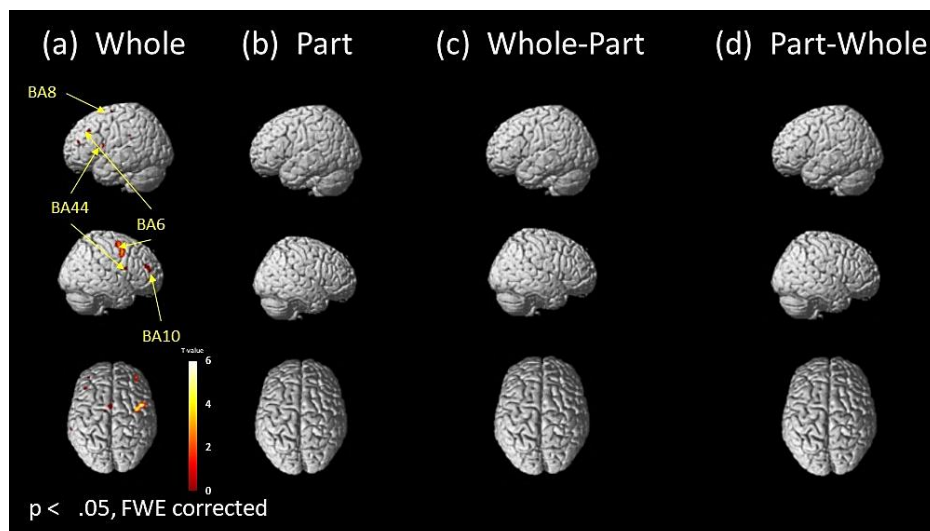


Figure 2. Subject A's brain activity area during imagery.

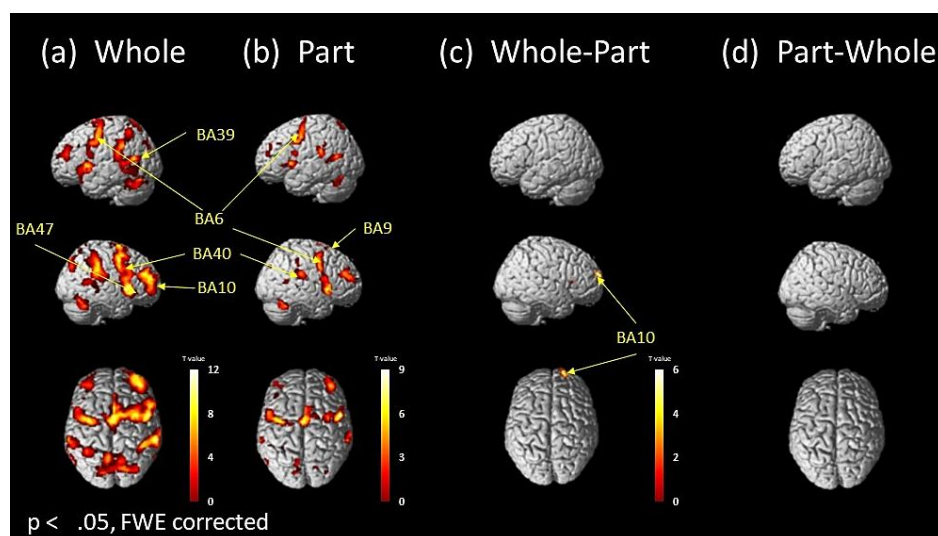


Figure 3. Subject B's brain activity area during imagery.

Participant B

During whole-method imagery, significantly greater activation than that at rest was observed in the left premotor cortex, (SMA), right angular gyrus, right frontal pole, right supramarginal gyrus, and right inferior prefrontal cortex. During part-method imagery, significant activation was observed in the bilateral premotor cortex, (SMA), right DLPFC, and right supramarginal gyrus. Significantly greater activation in the right frontal pole was detected during the entire imagery method than during the part methods. No regions showed significantly greater activation in the part method than in the entire method.

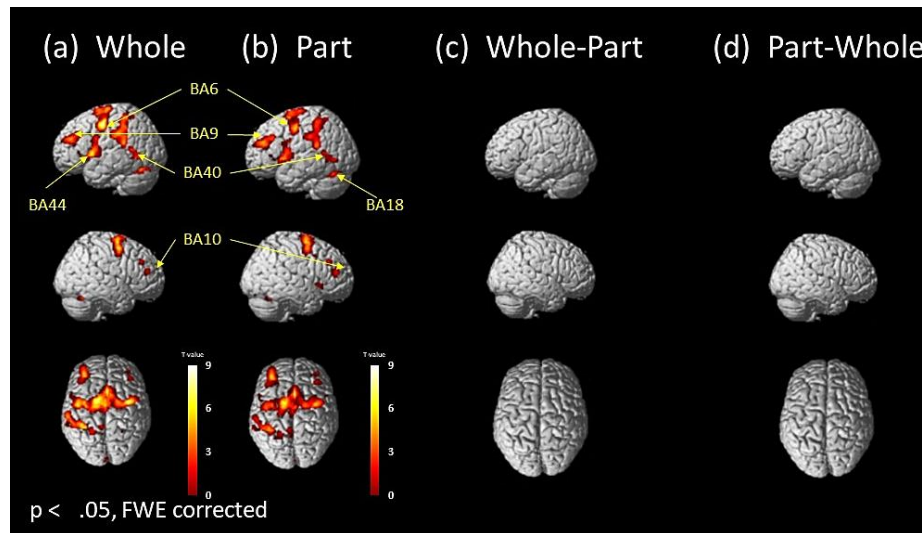


Figure 4. Subject C's brain activity area during imagery.

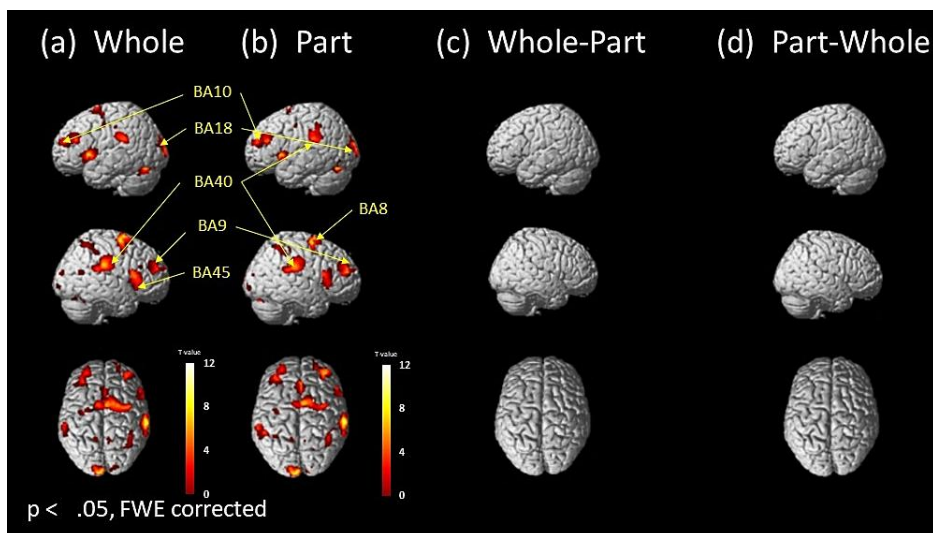


Figure 5. Subject D's brain activity area during imagery.

Participant C

During whole-method imagery, the following regions showed significantly greater activation than the other regions: the left premotor cortex, (SMA), left DLPFC, fusiform gyrus, supramarginal gyrus, inferior frontal gyrus (pars opercularis), and right frontal pole. During part-method imagery, significant activation was

observed in the left premotor cortex, (SMA), left DLPFC, insular cortex, secondary visual cortex (BA18), supramarginal gyrus, and left frontal pole. No statistically significant differences were observed between the whole- and part-method tasks.

Participant D

During whole-method imagery, significantly greater activation than that at rest was observed in the right DLPFC, right supramarginal gyrus, right inferior frontal gyrus (pars triangularis), left frontal pole, insular cortex, and secondary visual cortex (BA18). During part-method imagery, the following areas were significantly activated: right frontal eye field, right DLPFC, left frontal pole, secondary visual cortex, and bilateral supramarginal gyrus. No significant differences were observed in the contrast between the whole and partial imagery.

Results of introspective reports

Tables 4 and 5 summarize the participants' open-ended responses to the post-imagery questionnaire. Regarding task preferences, both participants A and B reported a greater affinity for the part method. Participants C and D preferred to use the whole method. Regarding imagery experience, participants A, B, and C referenced specific body parts and described the concrete kinaesthetic sensations they experienced during imagery. Participant D used abstract expressions to describe the imagery process, without specifying particular bodily sensations.

Table 4. Reflections regarding the whole and part method.

Participant A. I think I'm good at the part method. I believe that the part method is essential for improving performance.
Participant B. I am better at standing throw (part method). I am not good at coordinating the full sequence and prefers focusing on mastering the basic forms. Ultimately, I consider that the most effective training is eventually be able to bring the flow back to the basic forms.
Participant C. I prefer the whole method. As the whole method has a natural flow, it allows for overall smooth execution. I believe the whole method using the glide technique is more appropriate for training purpose, especially because it reflects actual competitive performance.
Participant D. I am better at the whole method, likely due to having focused on it more in prior training. However, when considering which approach is optimal through training, I concluded that the part method should be more important. This is because the whole method is an extension of the part method. I believe that as the part method approaches the ideal, the whole methods should be incorporated.

Table 5. Reflections on motor Imagery experience.

Participant A. During the part-method imagery, I could even imagine the sensation of tension extending to the tips of my toes and the muscles in my back. In the whole method, I couldn't make the vivid imagery of the areas where I often make mistakes. I found it difficult to grasp the finer details and the sensation of the shot put resting on my fingers.
Participant B. I felt differences in the sense of momentum, push-off, and the chest expansion between the two imagery types. Since I consciously felt the sensation of the trajectory of the shot flying through the air. I sensed a difference in the shot's trajectory.
Participant C. What I realized with this imagery experiment is that parts I can't actually do, I also can't do in my imagery. On the other hand, I was able to make imagery of the sensation of applying force to the soles of my feet and the image of my hand holding the shot put.
Participant D. By imaging two different movements, the amount of movement increases, so the difference in one's own movement retention level becomes more apparent. Furthermore, by performing this mental simulation without moving the body, one's own imagery ability is measured, and differences are also expected to appear between whole-body movement and segmented movement in this regard.

Results of the Japanese Movement Imagery Questionnaire-Revised (JMIQ-R)

Table 6 presents the results of JMIQ-R. The questionnaire assessed two types of motor imagery: kinaesthetic imagery (items 1, 3, 5, and 7) and visual imagery (items 2, 4, 6, and 8). Participants rated each item on a 7-point scale (1 = very difficult, 7 = very easy), and the total scores were calculated for each domain. For Participant A, the total score for visual imagery was 22, which was higher than the score for kinaesthetic imagery, which was 17. For Participant B, the total score for kinaesthetic imagery was 22, which was slightly higher than the score for visual imagery, which was 21. Participants C and D showed equal scores for kinaesthetic and visual imagery: 28 points for Participant C and 26 points for Participant D. Because total scores for kinaesthetic and visual imagery were identical for Participants C and D, it was not possible to determine which type of imagery was dominant in these cases.

Table 6. Results of Japanese version of the Movement Imagery Questionnaire-Revised (JMIQ-R).

	Participant A	Participant B	Participant C	Participant D
Item 1	3	6	7	7
Item 2	5	5	7	7
Item 3	5	6	7	6
Item 4	7	7	7	5
Item 5	5	4	7	7
Item 6	3	3	7	7
Item 7	4	6	7	6
Item 8	7	6	7	7
Kinaesthetic imagery	17	22	28	26
Visual imagery	22	21	28	26
Total	39	43	56	52

DISCUSSION

In this study to identify the brain regions recruited during motor imagery of shotput using the whole and part methods and to examine how these neural activations varied depending on individual athlete characteristics, the results support Hypothesis 1, as Participant B, who had both high performance and high task-specific expertise, demonstrated broader brain activation during whole-method imagery than during part-method imagery. In contrast, Hypothesis 2 was not supported because although Participants C and D were highly specialized but had lower competitive levels, they showed no significant differences in brain activation between the two imagery conditions. Hypothesis 3 was supported as Participant A, who had high athletic performance in a different event (hammer throw) but low specialization in shotput, showed minimal neural activation under both conditions.

Before interpreting the brain activation results in detail, it was necessary to examine the type of motor imagery that the participants performed. To address this issue, we evaluated introspective reports and results of the Japanese Movement Imagery Questionnaire-Revised (JMIQ-R). According to Hasegawa (2004), kinaesthetic imagery involves the sensation of performing one's own movements, whereas visual imagery involves observing one's movements from an external (third-person) perspective. Based on JMIQ-R scores, Participant A showed a clear preference for visual imagery. Participant B preferred kinaesthetic imagery. Participants C and D exhibit no discernible preferences. Meanwhile, considering previous literature that reported that the average total score for the JMIQ-R is approximately 43–45 (Hasegawa, 2004; Umeno & Kawano, 2015), the scores of Participants C (56) and D (52) were notably high, indicating exceptional imagery ability, regardless of modality. Further analysis of introspective reports revealed that Participants A, B and C described specific body parts and physical sensations, implying a tendency toward kinaesthetic imagery. Participant D used abstract descriptions, which made it difficult to determine the specific imagery strategy

employed. Combining these findings, Participant A showed an inconsistency between the JMIQ-R (dominant visual imagery) and introspection (kinaesthetic imagery). Participant B showed consistency as both data sources indicated kinaesthetic imagery. Participant C showed equivalent scores for both modalities on the JMIQ-R, with introspective data hinting at kinaesthetic imagery; however, the results remained inconclusive due to a lack of alignment. Participant D's imagery strategy could not be clearly identified, as both JMIQ-R scores were equal and the introspective reports were abstract. These discrepancies suggest that imagery strategies inferred from different assessment tools may not always align and, in some cases, cannot be clearly determined. Furthermore, the findings indicate that even if a participant scores highly on a standardized questionnaire, such as the JMIQ-R, the actual imagery strategy employed during tasks, as revealed through qualitative introspection, may differ, raising questions about the reliability of the subjective measures.

Previous studies reported that different types of imagery evoke different neural activation patterns (Binkofski et al., 2000). In line with this, the premotor cortex and supplementary motor area (BA6), which are commonly associated with kinaesthetic imagery (Guillot et al., 2009)—were activated in both the whole-method and part-method imagery in participants A, B, and C. In contrast, visual processing regions, such as the secondary visual cortex (BA18), which is known to be active during visual imagery (Guillot et al., 2009), were observed in participants C (part method) and D (both methods). These results imply that Participant B's neural activity patterns aligned with both their self-reported kinaesthetic imagery and the JMIQ-R assessment. For Participants A, C, and D, partial inconsistencies were observed between the subjective assessments and objective neural activation. This suggests that, for most participants (excluding B), there was a disconnect between perceived and actual imagery strategies, as inferred from the fMRI data. Nonetheless, the potential of fMRI for uncovering unconscious cognitive processes that are inaccessible through self-reporting offers significant advantages. These insights can inform the development of optimal imagery strategies to enhance athletic performance. In light of these results, the following section explores how neural activity patterns uncovered through fMRI and not otherwise observable can inform evidence-based training interventions and meaningfully contribute to real-world sports practice.

Characteristics of brain activity during motor imagery

Previous studies have shown that kinaesthetic motor imagery activates motor planning-related areas such as the premotor cortex and supplementary motor area (SMA, BA6) (Guillot et al., 2009). This type of imagery corresponds to what is referred to as kinaesthetic or first-person perspective motor imagery. In the present study, these areas were more active during whole-method imagery in Participants A, B, and C, and during part-method imagery in Participants B and C, compared to the rest. In contrast, in Participant D (whole method) and Participants C and D (part method), heightened activity was observed in the secondary visual cortex (BA18). This region is typically activated when motor imagery is based on visual input (Guillot et al., 2009), suggesting that, in these cases, imagery may have been constructed through visual (third-person perspective) representation, that is, visual imagery. Notably, in Participant C's part-method imagery, both BA6 (premotor/SMA) and BA18 (visual cortex) were significantly activated, indicating the coexistence of kinaesthetic and visual imagery strategies. This suggests that Participant C might have utilized visual cues to structure the imagery while simultaneously generating a kinaesthetic sensation. From these findings, we can infer that even under identical protocols and task instructions, individual participants may exhibit one of three distinct patterns of neural activation during motor imagery: dominant activation of motor-related areas, dominant activation of visual-related areas, or combined activation of both.

Looking more closely at individual differences, Participant A showed activation in the frontal eye field (BA8) during whole-method imagery. This region is known to be involved in directing attention to visual-spatial cues

(Kodaka et al., 1997). In this context, activation may reflect the internal visualization of an idealized shotput technique from a third-person perspective. Although Participant A had high athletic ability, his main event was the hammer throw, which required substantially different motor skills compared to shotput. As such, his engagement with shotput was limited to occasional competition with minimal training; thus, his specialization in shotput was low.

In contrast, Participants B–D considered the shotput to be their main event and regularly trained for it. In these individuals, activity was observed in the dorsolateral prefrontal cortex (DLPFC; BA9) under either or both imaging conditions. This region has been implicated in the retrieval of long-term memory and integration of cognitive and motor processes (Miyamoto et al., 2017). Therefore, it is likely that their imagery was grounded in stored motor experiences retrieved from prior training or performance. Thus, when imagining the part-method task (standing throw), regardless of the performance level, these participants likely reconstructed motor imagery using prior knowledge and memory. Conversely, Participant A, who lacked consistent shotput training and whose engagement was largely episodic, likely lacked the sensorimotor memory trace necessary for kinaesthetic imagery and hence relied on visual strategies. This may explain the absence of significant activation in the part-method condition.

Differences in brain activity between whole and part method motor imagery

Among the four participants, only Participant B exhibited a statistically significant difference between whole- and part-method motor imagery (Figure 3c). This suggests that distinct neural circuits were recruited for each imagery type in Participant B. The following discussion focuses on this case, along with the other participants (A, C, and D), who showed no significant differences.

Participant B demonstrated significantly greater activation in the frontal pole (BA10) during imagery using the entire method than during imagery using the parts method. According to Okuda et al. (2003), the frontal pole becomes prominently active when an individual not only visualizes a task but also actively anticipates how to structure the imagery, reflecting an advanced level of cognitive control. Given that Participant B was a specialist in shotput, regularly engaged in both practice and competition, and possessed elite competitive abilities, it is likely that she developed a refined motor representation for the glide technique. This advanced motor representation may have enabled him to engage the frontal pole more actively during whole-method imagery, using anticipatory planning and self-monitoring mechanisms to structure the imagery more effectively than during part-method imagery.

In contrast, Participant A showed no significant difference in brain activity between the two imaging methods. Although Participant A possessed a high level of athletic ability (e.g., placing in the national championships), his main event was the hammer throw, not the shotput. His participation in shotput was limited to occasional competitions with minimal regular training. While Reed (2002) reported that individuals with advanced motor skills can more easily generate motor imagery for corresponding actions, Participant A might have lacked the specific motor proficiency required to generate detailed imagery. Consequently, his imagery might lack sufficient granularity to elicit distinct neural activation patterns between the whole and partial methods.

Participants C and D showed no significant differences between the conditions despite being shotput specialists. However, their competitive performance levels were lower than those of Participant B. Furthermore, the activation patterns across the whole and part imagery were nearly identical, suggesting that these participants did not differentiate between the two imagery types in their mental representations. This uniformity may reflect limited motor representation differentiation or reduced metacognitive awareness of task segmentation.

Overall, three out of four participants did not exhibit significant differences in neural activation between whole and part motor imagery. These included one high-performing athlete with a low shotput specialization (Participant A) and two lower-performing specialists (Participants C and D). Only Participant B, a top-level athlete with high specialization, demonstrated greater neural recruitment during whole-method imagery. This implies that the degree of specialization and competitive performance may influence the extent to which neural activity distinguishes between the training approaches.

A limitation of this study was the inclusion of both male and female participants. Although we cannot entirely rule out sex differences in brain activity, prior research suggests that neuroplastic changes are more strongly influenced by experience and training than sex (Boyke et al., 2008; Imfeld et al., 2009). Therefore, it is reasonable to attribute the observed effects primarily to training history and motor expertise rather than to sex. Another inherent limitation common to motor imagery research is the difficulty in verifying the exact content of the imagery performed by each participant. Although subjective reports and psychometric assessments such as the JMIQ-R have been employed, actual mental processes remain partially opaque and not directly observable.

CONCLUSIONS

We identified the brain regions activated during whole- and part-method motor imagery tasks in shotput and examined how these activations varied according to individual differences in athletic specialization and performance level. The results revealed that in athletes with both highly competitive ability and specialization, whole-method imagery was associated with greater activation across broader brain regions. This suggests that whole-method training may be more effective, from a neurophysiological perspective, in such athletes. In contrast, part-method imagery was hypothesized to elicit greater brain activity in athletes with high specialization but lower performance levels. However, the results indicate no significant differences in neural activation between whole and part imagery in these individuals. Additionally, participant (A), who possessed high athletic ability but low specialization in shotput, exhibited limited brain activation under both imagery conditions. This finding suggests that neither the whole nor the part method offers a clear advantage in cases where both specialization and habitual training in the target skill are insufficient.

Importantly, this study highlights a methodological implication: Subjective measures, such as introspective reports or psychometric assessments (e.g., JMIQ-R), may not be sufficient to fully capture the nature of motor imagery strategies, particularly those occurring beneath conscious awareness. By contrast, objective assessments using fMRI can provide valuable insights into the neural processes involved in motor imagery. This opens up the possibility of identifying an athlete's implicit motor strategy and using this information to tailor individualized training interventions. Therefore, neuroimaging data may serve as practical and objective indicators for designing motor-training programs that align with each athlete's internal representation and cognitive tendencies. Given the case-based nature of this study, future research involving larger samples and more diverse populations is warranted to validate these findings.

AUTHOR CONTRIBUTIONS

IM conducted the study design, data collection, analysis and writing the manuscript. KN conducted the study design, data collection, analysis and editing the manuscript. SI conducted the study design, interpretation of the data, and editing the manuscript.

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