The influence of attentional focus on the development of skill representation in a complex action

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Objectives: Recent research has indicated that performers’ mental representation of a motor skill changes over the course of learning. In the present study, we sought to ascertain whether the type of instructions (instructions that emphasize either an internal or external focus of attention) influences the development of skill representation during motor learning.

Design: Participants without golf experience were recruited to practice a golf putting task over the course of three training days. Participants were randomly assigned to either an internal focus (focus on the swing of the arms; n = 10) or external focus (focus on the speed of the ball roll; n = 10) learning group. Changes in putting performance and mental representation structure were assessed over the course of learning, as well as during a follow-up retention test two days after practice.

Methods: Mental representation structure was measured employing the structural dimensional analysis of mental representations (SDA-M), which provided psychometric data on the structure of the mental representation in long-term memory. Additionally, the change in putting accuracy and consistency was recorded over the course of learning.

Results: Findings indicated that the external focus group performed with greater accuracy and consistency during training, and revealed a larger degree of development in their mental representation of the putting task.

Conclusions: Overall, our findings suggest that facilitating the link between an action and its effect by means of an external focus is crucial for motor performance as well as the development of skill representation.

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It has been well established that an individual’s focus of attention can have important implications for motor performance (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006; Wulf, 2007). That is, what an individual focuses on during the execution of a motor task can greatly influence the quality and accuracy of the movement. To this extent, research has demonstrated that an external focus of attention (i.e., focus on the effects of the movement on the environment) can lead to greater performance accuracy (e.g., Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), reduced attentional/working memory demands (e.g., Wulf, McNevin, & Shea, 2001), reduced brain and muscle activity (e.g., Zachry, Wulf, Mercer, & Bezodis, 2004), reduced susceptibility to choking under pressure (e.g., Land & Tenenbaum, 2012), and overall better outcome performance (e.g., McNevin, Shea, & Wulf, 2003) compared to an internal focus (i.e., attention directed to the performer’s own body movements) or irrelevant focus (i.e., attention directed to stimuli not pertaining to the task).

Furthermore, one’s focus of attention may also play an important role during the learning of a new motor skill. Research has indicated significant differences in motor skill acquisition as a result of how one focuses their attention (e.g., external or internal focus of attention) during learning (see Wulf, 2007). Traditionally, motor learning has been assumed to benefit from attention directed to the step-by-step components of skill execution (Wulf & McNevin, 2003). Instructions and feedback, therefore, are typically given to novices regarding various aspects of their movements. However, recent research suggests that skill acquisition is facilitated when attention is directed externally to the effects of one’s...
movement on the environment, and not the movements themselves (Castaneda & Gray, 2007; McNevin et al., 2003; Shea & Wulf, 1999).

One such study that demonstrated the learning advantage of an external focus was conducted by Wulf et al. (1999). In the study, novice participants were required to practice a golf pitch shot under learning instructions that emphasized either an internal focus or an external focus of attention. Specifically, the internal learning group was instructed to focus on the swinging motion of their arms. In contrast, the external learning group was instructed to focus on the swinging of the golf club. Results from the study indicated that learners who adopted an external focus significantly outperformed (i.e., high accuracy scores) those who adopted an internal focus of attention during learning. Furthermore, a subsequent retention test on the following day revealed that the external learning group maintained a performance advantage even when no focus instructions were given. Similar findings were also reported by Wulf and Su (2007).

The comparative learning benefits associated with an external focus compared to an internal focus have been observed across a variety of tasks such as ski simulators (Wulf, Höß, & Prinz, 1998), golf pitch shots (Wulf et al., 1999), soccer throw-ins (Wulf, Chvílackowsky, Schiller, & Ávila, 2010), and tennis backhands (Maddox, Wulf, & Wright, 1999). These learning benefits have been argued to result from promoting movements supported by automatic motor control processes, whereas, an internal focus is suggested to be ineffective and delay learning due to the conscious interferences with normal and automatic motor control processes (i.e., constrained action hypothesis; McNevin et al., 2003; Wulf, McNevin, et al., 2001; Wulf, Shea, & Park, 2001). Additionally, the benefits associated with an external focus have been linked to the coding of motor actions in long term memory. Drawn from the principles of ideomotor theory (James, 1890; Lotze, 1852), Prinz’s (1990), common-coding theory postulates that actions are represented in terms of their perceptual effects in the environment. Furthermore, it is suggested that a commonality exists between the representations underlying perception and action such that the anticipation of the perceptual consequences of an action act to prime the intended motor execution (see Hommel, Müßeler, Aschersleben, & Prinz, 2001).

Given that focusing on the effects of one’s movements on the environment is thought to prime the associated motor execution, it is also likely that this same kind of focus is beneficial for acquiring the underlying sensorimotor representation linking actions to their effects (Hommel, 2007). That is, an external focus may also facilitate the integration of effector and perceptual processes during motor learning, and play an important role in the development of one’s sensorimotor representation (Weigelt, Schack, & Kunde, 2007).

During practice, researchers have suggested that task specific cognitive representations are acquired which act to guide the planning and execution of actions (Ericsson, 2007; Hommel et al., 2001; Schack & Ritter, 2013; Schmidt, 1975, 1976). According to the cognitive action architecture approach (CAA-A, Schack, 2004; Schack & Mechsner, 2006; Schack & Ritter, 2009), motor learning is considered as the modification and adaptation of such representation structures in memory. Specifically, Schack and Mechsner (2006) suggest that the representation of complex actions are organized within hierarchical memory structures comprised of cognitive units, referred to as basic action concepts (BACs). These BACs represent particular body postures (key elements of movements) and correspond to perceptual effects of movement events in order to organize motor coordination. Therefore, they are seen as cognitive tools in realization of action goals. Within the cognitive architecture of action, BACs are stored at a representational level and code the movement structure at a given level of expertise. Consequently, BACs are considered the major building blocks of cognitive representations, with the chunking and hierarchical ordering of the BACs reflecting the degree of expertise associated with a particular motor action. A number of studies have shown, that motor expertise is functionally related to the degree of order formation of BACs in memory (e.g., Bläsing, Tenenbaum, & Schack, 2009; Schack & Hackfort, 2007). Similarly, Elsner and Hommel (2001) propose that actions are controlled via representational units comprised of integrated motor structures along with their perceptual consequences.

In order to investigate the structure of these representations in memory, Schack and Mechsner (2006) employed an experimental approach to examine differences in the structure of mental representations between expert, low-level, and novice tennis players. In their study, the authors investigated the players’ mental representation of a tennis serve using the structural dimensional analysis of mental representation (SDA-M; Schack, 2004; 2012). The SDA-M analysis identifies the structural composition of skill representation through revealing the hierarchical and temporal structure of BACs within long-term memory. Findings from the study indicated that experts’ representations were more elaborate compared to the non-experts’ representations. Specifically, experts’ representations were organized in a distinctive tree-like structure comprised of clusters of BACs relating to the biomechanical task demands, whereas the representations of novices and low-level players were organized less hierarchically and were unrelated to the functional demands of the task. In addition, experts’ representations were highly similar across individuals, while lower skilled participants’ representations were more varied. These findings highlight the significant differences in skill representation between performers of differing skill levels.

Similar differences in representation structure between experts and novices have been found across a variety of complex motor skills such as windsurfing (Schack & Hackfort, 2007), judo (Weigelt, Ahlmeier, Lex, & Schack, 2011), and dance (Bläsing et al., 2009), as well as in manual action tasks (e.g., Stöckel, Hughes, & Schack, 2011) and within special populations (e.g., stroke rehabilitation; Braun et al., 2007). The striking differences in representations found between performers of different skill levels support the assumption that motor learning leads to the development of skill representations which play an important role in the control and organization of actions (e.g., Elsner & Hommel, 2001).

As a more direct test of this assertion, Frank, Land, and Schack (2013) recently investigated the development of mental representation structures during the early skill acquisition of a complex motor task. Using a longitudinal design, a group of novices practiced a golf putting task over the course of five training days. The structure of the participants’ skill representations were assessed before and after training. Results indicated that along with improved putting proficiency, significant changes emerged within the practice group’s mental representation. Specifically, prior to practice, no functional structure was evident within the group’s mental representation. However, after considerable task experience, the practice group’s representation structure reflected a shift towards a hierarchical organization of action concepts similar to that of more skilled players. In contrast, a control group, who did not practice the golf task, did not reveal any significant changes in skill representation between pre- and post-testing. These findings support the notion that functional adaptations of motor skill representations (i.e., changes in the representation structure which more closely resembles the movement phases of the motor skill) are closely tied to motor learning.

While motor skill acquisition has been shown to be accompanied by the formation of representation structures in long term memory, it is currently unclear how different foci of attention affect
the relative development of one’s representational structure in the context of motor performance. Given that the sensory consequences of motor actions are considered an important component within sensorimotor representations (e.g., Ford, Hodges, & Williams, 2007), it may be likely that adopting an external focus during learning may facilitate the integration of perceptual effects during the formation of one’s skill representation leading to a more refined representation structure. To explore this hypothesis, the purpose of the present study was to investigate the effect of different foci of attention on the formation and development of representation structures in long-term memory. More specifically, participants trained on a golf putting task under specific instructions to focus either on the swing of their arms (internal focus) or the velocity of the ball (external focus) over the course of three days. Differences in the participants’ representational structure were examined via SDA-M before and after task practice and later during a follow-up retention test. It was predicted that training under an external focus would lead to better performance while also resulting in more elaborate memory structures consisting of hierarchical organized chunks of BACs functionally related to the motor structure of the movement.

Method

Participants

Twenty students were recruited to participate in the present study. All participants were novice golfers with little to no previous golf experience. They were randomly assigned to either an internal focus on the swing of their arms and hands (cf. Bell & Hardy, 2009; Staudinger, 2004) or an external focus on the velocity of the ball (Bell & Hardy, 2009) during a follow-up retention test. It was predicted that training under an external focus would lead to better performance while also resulting in more elaborate memory structures consisting of hierarchical organized chunks of BACs functionally related to the motor structure of the movement.

Apparatus and SDA-M

Golf putts were performed on a 4 × 9 m artificial indoor putting green to a simulated golf hole, which consisted of a thin black disc equal in size to a regulation golf hole (i.e., 10.8 cm in diameter). Participants performed the golf-putting task using a Taylor Made golf putter (TM-110) and Wilson Staff golf balls. The golf balls were produced and whose edges had a negative or positive sign depending on whether the elements were assigned or not assigned according to an individually given similarity criterion (e.g., similarity or dissimilarity between concepts). BACs for the putt used in the present study were: (1) align shoulders parallel to target line, (2) align club face square to target line, (3) look to the hole, (4) rotate shoulders away from the ball, (5) sweep club away from the ball, (6) smooth transition, (7) rotate shoulders towards to ball, (8) accelerate club, (9) impact with the ball, (10) club face square to target line, (11) rotate shoulders through the ball, (12) sweep club past the ball, (13) look to outcome, and (14) decelerate club. The BACs for the present study were adopted from Frank et al. (2013), and further refined by a golf expert to improve clarity and accuracy.

Participants were instructed to sort the lists of BACs according to their functional relevance during movement execution, i.e., whether or not two given BACs are related to one another while performing the movement. After all judgments were made with a particular anchor concept, another concept occupied the anchor position, and all other concepts were compared to the new anchor. As each concept took the position of anchor once, we obtained a total of N (14) decision trees whose nodes contained the subsets produced and whose edges had a negative or positive sign depending on whether the elements were assigned or not assigned to the anchor concept.

Task and procedure

Participants trained on a golf putting task over the course of three days, followed by a retention test two days later. The putting task consisted of golf putts performed randomly from five distances equally spaced between 2 m and 5 m (2.0, 2.75, 3.5, 4.25, and 5.0 m). The object of the task was to putt the ball as close as possible to the golf hole.

At the start of training on day one, participants were shown a video demonstrating the golf putting task. The video consisted of an expert performer executing three putts. Next, participants completed the SDA-M for the golf putt. Following, participants again watched the video during which the specific attentional focus instructions consistent with their assigned learning group were given. Next, participants took ten warm-up putts (2 putts from each location) prior to training. For each of the three days of training, participants performed 180 total training putts (6 blocks of 30 putts; 6 putts from each of the 5 locations per block). The order of the putts were randomized within each block over the 5 distances. A computer monitor adjacent to the putting green displayed a number (1–5) that corresponded to the start location of the upcoming putt. Participants were given a short break in between blocks, at which time they completed the manipulation check questionnaire. After the third and final day of training, participants again completed the SDA-M.

Internal focus

Participants in the internal learning condition were instructed to focus on the swing of their arms and hands (cf. Bell & Hardy, 2009; W.M. Land et al. / Psychology of Sport and Exercise 15 (2014) 30–38
performed to transform the set of items into a dendrogram. For all
experiments, a hierarchical cluster analysis was
formed. In a second step, a hierarchical cluster analysis was
determined as associated) and negative (concepts judged as not asso-
ciated, algebraic sums were computed for the positive (concepts
judged as associated) and negative (concepts judged as not asso-
ciated). As a result, participants were reminded of the focus instructions after each block of putting, as well as a visual reminder “firm wrists” (“Feste Handgelenke” in
German) was displayed on the computer monitor below the next
trial location number.

External focus
Participants in the external learning condition were instructed
to focus on the proper trajectory and speed of the ball rolling to
the hole (cf. Bell & Hardy, 2009; Land, Tenenbaum, Ward, & Marquardt,
2013; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). The participants
were reminded of the focus instructions after each block of putting, as well as a visual reminder “speed of ball roll” (“Geschwindigkeit
des Balles” in German) was displayed on the computer monitor
below the next trial location number.

A retention test was given two days following the final practice
day. All participants performed a final 30 putts (preceded by 10
warm-up putts; 2 from each location), as well as the SDA-M. No
focus of attention instructions or reminders were given on the last
day.

Post experimental manipulation check

After completing each block of putting, a questionnaire
designed to gauge the extent to which the participants adopted the
attentional focus strategies (adapted from Bell & Hardy, 2009) was
administered to the participants. To examine adoption of the
attentional focus instructions, they were asked to respond on a
Likert scale ranging from 1 (not at all) to 5 (very much so) to the
following two questions: (1) “to what extent were you focused on
the movements of any part of your body during putting?”, and (2)
“to what extent were you focused on the speed of the ball rolling to
the hole?”

Dependent measures and data analyses

Outcome performance. To quantify outcome performance, the
coordinates for the outcome location of each putt was recorded.
From these coordinates, the mean distance each putt finished from
the target (i.e., mean radial error), and the consistency in outcome
locations (i.e., bivariate variable error) were calculated. Mean radial
error (MRE) was calculated as the average distance of each putt
outcome from the center of the target, in centimeters. For consist-
tency, bivariate variable error (BVE) was calculated by the square
root of the k shots’ mean squared distance from their centroid (see
Hancock, Butler, & Fischman, 1995). To examine putting perfor-
mance, a 2 × 19 (group by block) mixed-design analysis of variance
(ANOVA) with group as a between subjects factor and block as a
within subjects factor was performed on each of the two perfor-
mance measures. Finally, a priori planned comparisons were con-
ducted for each measure on the retention test performance of the
two learning groups. The Greenhouse-Geisser adjustment to df and
significance was employed whenphericity did not hold.

Mental representation structure
Based on the participants’ decisions during the splitting pro-
dure, algebraic sums were computed for the positive (concepts
judged as associated) and negative (concepts judged as not asso-
ciated) subsets of each decision tree, and subsequently z trans-
formed. In a second step, a hierarchical cluster analysis was
performed to transform the set of items into a dendrogram. For all
cluster analyses conducted, a critical value \( d_{crit} = 3.41 \) was chosen
resulting from an alpha-level of \( \alpha = .05 \). BACs linked together above
this critical value were considered irrelevant, while BACs linked
below this value (i.e., Euclidean distances below 3.41) were
considered related. Next, differences between representation
structures were examined across pre, post and retention tests, as
well as between the internal and external focus conditions. Spe-
cifically, in order to compare differences between representation
structures, a within- and between-group comparison of the cluster
solutions was performed by determining the structural invariance
(\( \lambda \)) between cluster solutions. According to Lander (1991),
two cluster solutions are significantly different (i.e., variant) for \( \lambda < .68 \),
which corresponds to an alpha level of \( p = .05 \); while two cluster
solutions are invariant for \( \lambda \geq .68 \). In addition, the similarity of each
group’s mental representation structure with that of an expert
representation structure was calculated using the Adjusted Rand
Index (ARI; Rand, 1971; Santos & Embrechts, 2009). More specif-
ically, the mental representation of an expert, which reflected well
the putting movement and its phases, was used as a reference for
ARI calculations. The ARI serves as a measure of similarity on a
range between –1 and 1, with larger values indicating a greater
degree of similarity between two cluster solutions.

Manipulation check

Similar to Bell and Hardy (2009), both between- and within-
group comparisons were used to analyze attentional focus adop-
tion. A between-group approach was utilized to determine whether
or not the internal and external groups differed in their response to
each of the two questions (e.g., whether the external group focused
more on the speed and the internal group focused more on their
body movements). For the comparison between groups, separate
2 × 4 (condition by day) repeated measures ANOVAs with condi-
tion as a between-subjects (BS) factor and day as a within-subjects
(WS) factor were performed for each test item separately. A within-
subject approach was additionally utilized to determine whether or
not a participant would report a greater adoption of the relevant
attentional focus consistent with their assigned group (e.g.,
whether a participant in the internal focus group would rate higher
on adopting a focus on body movements compared to the speed of
the putt). For the comparison within each group, separate 2 × 4
(item by day) repeated measures ANOVAs with item and day as WS
factors were performed for each group separately.

Results

Manipulation checks

To assess whether the participants had adopted the assigned
attentional focus, responses to the two Likert rated attention
questions were analyzed.

Between-group analysis

For item 1 (focus on body), the omnibus RM ANOVA indicated a
significant main effect of Condition, \( F(1, 18) = 48.14, p < .001 \),
\( \eta^2_p = .73 \), and more importantly a significant Condition by Day
interaction, \( F(3, 54) = 16.72, p < .001, \eta^2_p = .48 \). Subsequent pair-
wise comparisons performed for each day indicated that the in-
ternal focus group reported significantly greater focus on the body
compared to the external group during all three practice days (all
p’s < .001). However, on the final day of performance (retention

\footnote{2 For more details on the SDA-M analysis, please see Schack (2012).}

\footnote{3 The expert golfer held a United States Golf Association handicap of +.2, and had
20 years of competitive golf experience.}
test) no significant differences ($p = .176$) were observed between the two groups and their reported focus on body movements (see Table 1).

Similarly, the Condition by Day RM ANOVA on item 2 (focus on speed) indicated a significant main effect for Condition, $F(1, 18) = 13.38$, $p = .005$, $\eta^2 = .43$. Specifically, the external focus group reported adopting a greater focus on the speed of the ball compared to the internal focus group across all days (see Table 1).

Within-subjects analysis
A significant Item $\times$ Day interaction was revealed for each of the RM ANOVAs, $F(3, 27) = 3.50$, $p < .029$, $\eta^2 = .28$ for the internal group; $F(3, 27) = 7.74$, $p < .001$, $\eta^2 = .46$ for the external group. Follow-up pairwise comparisons performed for each day revealed that participants in the internal group reported focusing on body movements more so than the speed of the putt during the practice phase of the experiment (all $p's < .05$). In contrast, the external focus group reported a greater focus on the speed of the ball than on body movements for each day of practice (all $p's < .05$). For the final test day in which no focus instructions were given, neither the internal group ($p = .523$) nor external groups ($p = .130$) reported adopting a greater use of either an external or internal focus of attention (see Table 1).

Outcome performance
Outcome performance was assessed in terms of both accuracy (i.e., MRE) and performance consistency (i.e., BVE).

Accuracy
Mean accuracy scores across both training and retention phase are illustrated in Fig. 1. A $2 \times 19$ (group by block) mixed-model ANOVA indicated a significant main effect for block, $F(4.03, 72.60) = 10.60$, $p < .001$, $\eta^2 = .37$, as well as, a significant main effect for group, $F(1, 18) = 7.83$, $p = .012$, $\eta^2 = .30$. However, the Group $\times$ Block interaction failed to reach significance, $F(4.03, 72.60) = 1.87$, $p = .136$, $\eta^2 = .09$. As can be seen in Fig. 1, performance for both groups improved over the course of practice. Furthermore, the performance of the external learning group was significantly better than the performance of the internal learning group.

Although the external focus group demonstrated greater accuracy during training, on the final retention test, a planned comparison indicated only a trend towards statistical significance for an effect of learning group, $t(18) = 3.75$, $p = .069$, $d = 1.77$ (see Fig. 1). While this effect was not significant, the large effect size may suggest a lack of statistical power to detect a real difference between the two conditions (Cohen, 1992).

Outcome consistency
A $2 \times 19$ (group by block) mixed-model ANOVA indicated a significant main effect for block, $F(7.34, 132.04) = 12.72$, $p < .001$, $\eta^2 = .41$, as well as, a significant main effect for group, $F(1, 18) = 8.65$, $p = .009$, $\eta^2 = .33$. However, a significant Group $\times$ Block interaction was not found, $F(7.33, 132.04) = 1.57$, $p = .146$, $\eta^2 = .08$. As illustrated in Fig. 2, the consistency of performance improved for both groups over practice, with the external focus group displaying significantly more consistent performance over the course of training.

Similarly, the external focus group demonstrated significantly more consistent performance during the retention test compared to the internal focus group. Specifically, an a priori planned comparison indicated a significant effect of learning group, $t(18) = 7.18$, $p = .015$, $d = 3.38$ (see Fig. 2).

![Fig. 1. Average distance from the target (MRE) for each block of practice (Day 1 - Day 3) and retention.](image)

![Fig. 2. Bivariate variable error scores for each block of practice (Day 1 - Day 3) and retention.](image)

Table 1
Mean (s) responses to the manipulation check questions across each study day for both internal and external learning groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Item</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>I1</td>
<td>4.27 (.47)</td>
<td>4.28 (.80)</td>
<td>4.25 (.69)</td>
<td>3.47 (.34)</td>
</tr>
<tr>
<td></td>
<td>I2</td>
<td>3.38 (.49)</td>
<td>2.85 (.71)</td>
<td>3.1 (.98)</td>
<td>3.2 (.122)</td>
</tr>
<tr>
<td>External</td>
<td>I1</td>
<td>2.85 (.97)</td>
<td>2.30 (.73)</td>
<td>2.00 (.76)</td>
<td>3.73 (.49)</td>
</tr>
<tr>
<td></td>
<td>I2</td>
<td>4.01 (.68)</td>
<td>4.37 (.53)</td>
<td>4.30 (.72)</td>
<td>4.20 (.78)</td>
</tr>
</tbody>
</table>

Note: I1 represents the responses to the question “to what extent were you focused on the movements of any part of your body during putting?” I2 corresponds to the question “to what extent were you focused on the speed of the ball rolling to the hole?” Responses were made on a Likert scale ranging from 1 (not at all) to 5 (very much so).

Fig. 1. Average distance from the target (MRE) for each block of practice (Day 1 – Day 3) and retention.

Fig. 2. Bivariate variable error scores for each block of practice (Day 1 – Day 3) and retention.
Mental representation structure

The dendrograms presented in Figs. 3 and 4 display the mean representation structures for each learning group at pretest, posttest, and retention. As can be seen in Figs. 3a and 4a, neither the internal nor external focus learning group displayed any distinct clustering of basic action concepts prior to training. All branches of the dendrograms were above the critical value of $d_{crit} = 3.42$ (based on a significance level of 5%). However, discernible differences in structure existed for both learning groups after the third day of training (i.e., posttest). Specifically, the internal learning group’s mean dendrogram displayed two significant clusters ($p < .05$) with the first cluster pertaining to the backswing phase of the putt (consisting of BACs 4 & 5: “rotate shoulders away from the ball” & “sweep club away from the ball”) and the second cluster pertaining to the forward swing phase of the putt (BACs 9 & 12: “impact with the ball” & “sweep club past the ball”) (see Fig. 3b). Similarly, the mean dendrograms for the external learning group displayed significant changes over the course of practice. Three distinct clusters were revealed at the end of the practice phase ($p < .05$) (see Fig. 4b). These three clusters related to the functional phases of the putting stroke which consisted of the movement preparation phase (BACs 1, 2, 3, & 10: “align shoulders parallel to target line”, “align club face square to target line”, “look to the hole”, & “club face square to target line”), the back swing phase (BACs 4 & 5: “rotate shoulders away from the ball” & “sweep club away from the ball”), and finally the forward swing phase (BACs 9, 11, & 12: “impact with the ball”, “rotate shoulders through the ball”, & “sweep club past the ball”).

While both groups displayed the formation of discernible memory structures from pre to posttest, statistical analysis of invariance indicated that the structures were significantly different from one another ($\lambda = .43$; $\lambda_{crit} = .68$; for more details, see Schack, 2012). In order to examine whether this difference relates to a more functional development for the external learning group, adjusted rand index (ARI) values were calculated to indicate the degree of similarity between each learning group and an expert memory structure. Results indicated that the memory structure of the external learning group was more similar to that of the experts (ARI = .25) compared to the internal learning group (ARI = .06). Thus, the memory structure of the external learning group can be understood to have had a larger functional change compared to that of the internal learning group.

Examination of the memory structures from posttest to retention indicated little to no change for either of the two learning groups (see Figs. 3c and 4c). For the internal learning group, no changes were evident in the identified clusters from the post-test ($\lambda = 1$; $\lambda_{crit} = .68$). For the external learning group, only one change from post-test was observed. Specifically, the BAC, “club face square to target line” was no longer associated with the movement preparation phase. However, this exclusion did not result in a significant difference between the memory structure at post-test and retention ($\lambda = .69$; $\lambda_{crit} = .68$). Again, comparison of the memory structures at retention with the expert memory structure indicated that the external learning group’s representation was more similar to that of the experts (ARI = .44) compared to the internal learning group’s representation (ARI = .06). Thus, it appears that the functional changes that occur at the representational level as a function of learning remain stable over time.

Discussion

The primary purpose of the present study was to examine the changes in the cognitive representation of golf putting over the course of learning under instructions that emphasized either an internal or external focus of attention. Consistent with our hypothesis, learners who adopted an external focus of attention during training indicated greater putting accuracy and consistency compared to learners who were instructed to adopt an internal focus of attention. Similarly, a follow-up retention test indicated that the external learning group was significantly more consistent in their putting outcomes, with a trend towards greater accuracy. These findings replicate a large body of research supporting the performance benefits associated with instructions that induce an external focus of attention (for a review, see Wulf, 2013). More importantly, however, along with improved putting performance, the results of the SDA-M analysis indicated that the cognitive representations of the external focus learners were more elaborate, better reflected the biomechanical demands of the task, and were more similar to the representations of expert golfers.

Prior to training on the golf putting task, both the external learning group and the internal learning group displayed a lack of organization in their cognitive representation of the golf putt. That is, neither group revealed significant clustering of basic action concepts in long term memory. However, after three days of task practice, the emergence of functional structures of basic action concepts (i.e., clusters pertaining to a specific movement phase) were evident in both the internal and external learning groups. For both learning groups, these clusters were related to the biomechanical demands and functional phases of the putting task. Specifically, two discernable clusters pertaining to the backswing
phase and forward swing phase of the golf putt were revealed in the memory structure of the internal learning group. However, the external learning group displayed a significantly more elaborate cognitive representation consisting of three functional clusters relating to the preparation phase, backswing phase, and forward swing phase of the golf putt. Subsequent comparison with the memory structure of an expert representation revealed that the structure of the external learning group was more similar to the ideal representation than those of the internal learning group.

These findings are in line with a number of studies which have examined the cognitive representations of complex movements (e.g., Bläsing et al., 2009; Schack & Mechsner, 2006; Weigelt et al., 2011). Specifically, differences in skill level have been reliably shown to result in discernible differences in memory structures between novices and experts such that high level skill is associated with memory structures that are organized in a distinct tree-like hierarchy and are well matched to the biomechanical demands of the task (Schack & Mechsner, 2006). In contrast, low skilled performers have been shown to have memory structures which are less hierarchically organized with structures unrelated to the functional demands of the task (Bläsing et al., 2009). More closely related, the work of Frank et al. (2013) provided evidence for the development of representational structures over the course of motor learning. Similar to the findings in the present study, participants displayed no significant structure within their mental representation at the onset of training. However, after training, the practice group displayed clear signs of representation development with functional clusterings of BACs related to the biomechanical phases of the golf putt. These findings along with the findings of the current study support the idea that motor learning can be considered in terms of the modification and adaptation of representation structures in long term memory (e.g., Elsner & Hommel, 2001; Schack & Ritter, 2009). Furthermore our results indicate an overlap between the adaptation of motor performance and modification of memory representation within the course of motor learning.

In general, results from the present study support the assumption that focusing on the external effects of an action during motor learning plays an important role in the development of one's representation structure. Specifically, learners who adopted an external focus during learning revealed more elaborate representations than those who adopted an internal focus. Research has demonstrated that the sensory effects of an action are an important part of one's representation (e.g., Koch, Keller, & Prinz, 2004). To this extent, learning the associations between an action and its effect is seen as a crucial component of skill acquisition (Elsner & Hommel, 2001). According to Elsner and Hommel's (2001) two-stage model for motor learning, the first stage of learning is the acquisition of contingencies between a movement and its effect. In this regard, acquiring these associations lead to the formation of cognitively represented sensorimotor components which form the basic functional units of action representation (Hommel & Elsner, 2009). Furthermore, extended practice has been found to lead to stronger associations between an action and its effect (e.g., Elsner & Hommel, 2001; Kunde, Hoffmann, & Zellmann, 2002; Kunde, Koch, & Hoffmann, 2004; Prinz, 1997).

Consistent with this ideomotor viewpoint, we suggest that the benefit associated with an external focus is due in part to the enhanced integration of effector and perceptual processes brought about by focusing on the sensory consequences of the movement. Facilitating the cognitive association between an action and its effect is viewed to have lead to the development of more elaborate sensorimotor representations (i.e., clusterings of BACs) as the motor system would be more sensitive to the perceptual consequences of the motor action. In contrast, adopting an internal focus during learning would hinder the ability of the system to make associations between the movement and its effect, leading to less elaborate sensorimotor representations as observed in the current study. Additionally, once the association between an action and its effect has been integrated within the representation, the anticipation of the movement effect becomes an effective retrieval cue of the associated movement (Stage 2 of Elsner and Hommel's model), which further aids performance (Hommel & Elsner, 2009).

Interestingly, with respect to putting performance, the external focus manipulation resulted in a rather immediate performance advantage for the external focus condition. Consistent with these findings, a number of studies have likewise observed performance advantages during the early stages of training associated with an external focus (e.g., Totsika & Wulf, 2003; Wulf et al., 1999; Wulf, Weigelt, Pouler, & McNevin, 2003; Exp. 1). Thus, our findings appear to be no exception. However, given the lack of baseline performance testing prior to providing the attentional focus instructions, it cannot be completely ruled out that the initial performance advantage displayed by the external focus condition is due instead to initial skill-level differences between the two conditions. Nonetheless, there are reasons to suspect that the differences observed between the two conditions are in fact solely related to the attentional focus manipulation rather than pre-existing skill-level differences. Primarily, the lack of differences in the representation structures between the internal and external focus conditions prior to training suggests that each group was equivalent at baseline, as representation structures have been shown to be tightly coupled to performance levels (Frank et al., 2013). Furthermore, all participants were randomly assigned to the putting conditions, and no significant differences in the
amounts of previous golf experience were identified between the two groups. Thus, given these controls, it would seem unlikely that pre-existing skill-level differences could account for the performance advantage displayed by the external focus condition.

With respect to the follow-up retention test, little to no change in the memory structures of the two groups were observed, which suggests that these changes are relatively permanent. This finding is consistent with the literature on motor learning which states that the learning process results in “relatively permanent” change (Guthrie, 1952). However, it would be important for future research to track the development and retention of cognitive representations over an extended time period to confirm these findings. In this direction, it would also be informative to examine whether the training advantages of an external focus, both in terms of performance and skill representation, persist relative to an internal focus over training periods spanning months or years. In the present study, the performance gap between the internal and external focus condition at retention narrowed compared to performance during the training phase. This result possibly suggests that the performance of the internal focus condition may catch up to the performance of the external focus condition over an extended period of training. However, the decreased performance difference between these two conditions may also result from the lack of attentional focus instructions given during the retention test. Given that the two conditions did not show differences in their adopted focus of attention during retention, it is not surprising that their performance was less dissimilar. This account further supports the importance of attentional focus instructions during learning and performance, as participants tend to adopt an internal focus of attention when not prompted to attend externally (Land et al., 2013). We would further suggest that the performance differences that do exist at retention, despite the lack of differences in adopted attentional focus, highlight the influence of previously acquired skill representations.

Conclusion

The present study extends a long line of research supporting the learning benefits associated with an external focus of attention. Specifically, findings from the study indicate that facilitating the link between an action and its effect by means of an external focus is important for motor performance as well as the development of skill representation. While these findings provide important insights into the mechanisms behind skill acquisition, more research on the factors that influence the development of skill representations over the course of learning is needed. For instance, the influence of implicit and explicit learning on representation development would be an interesting and insightful step in this direction.

Importantly, the present study also provides evidence for the utility of the SDA-M method to distinguish between representation structures of similarly skilled participants. Largely the research employing SDA-M has been geared towards examining differences between experts and novices or groups that vary largely in task performance. However, the present study indicates that this method is also useful for identifying differences in memory structures when differences in outcome performance are more subtle. As a result, this method may prove useful in future research to distinguish the training factors critical for the development of skill representations, and thus expert performance.

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References


