The Effects of Combining PETTLEP Imagery and Action Observation on Bicep Strength: A Single-Case Design.

The Effects of Combining PETTLEP Imagery and Action Observation on Bicep Strength: A Single-Case Design

Abstract

The PETTLEP model of motor imagery (Holmes & Collins, 2001) has been shown to be effective in enhancing strength performance. With recent literature discussing the shared neural substrates between imagery and action observation, this study investigated whether PETTLEP imagery would improve bicep strength both with and without an additional observational aid. Using a single-case design, four participants completed a baseline phase followed by PETTLEP imagery with and without an observation aid in a counterbalanced manner. Weekly bicep curl 1 repetition maximum (1 R.M.) was used as the performance measure. Results indicated that using an observational aid in conjunction with PETTLEP imagery can aid performance, but not to a greater degree than PETTLEP imagery alone. This indicates that observational aids may not be an essential addition to imagery interventions, but their inclusion is not detrimental. The study highlights further the benefit of using PETTLEP imagery for enhancing strength performance, which should be considered by practitioners delivering resistance training programs. Future research could further explore the role of observation when combined with imagery to assess the effect on strength in an athletic population.

Motor imagery is the act of producing an internal representation of movement, typically without generating any physical output (Mulder, 2007). Improvements in strength performance following the use of motor imagery are well documented in the literature (see Slimani, Tod, Chaabene, Miarka, & Charmari, 2016 for a review). For example, Yue and Cole (1992) found that a four-week training program using either maximal isometric contractions or imagined maximal isometric contractions produced strength gains of 29.8% and 22% respectively in the abductor digiti minimi muscle. A more recent study (Wright & Smith, 2009) on a larger muscle group (elbow flexors) also showed a strength gain of 23% through imagery training.

Such findings are potentially of great value to those involved in strength training. However, the question of how to conduct imagery to produce optimal strength gains also needs to be considered. The PETTLEP model (Holmes & Collins, 2001) has recently been used to guide imagery interventions with strength tasks (for example, see Wakefield & Smith, 2011). This model was derived from a mix of cognitive psychology, sport psychology and neuroscience research, the latter indicating that imagery produces activity in similar areas of the brain to those active during movement execution. Consequently, the model proposed that a 'functional equivalence' exists between imagery and physical performance of a motor skill. PETTLEP is an acronym, with each letter standing for a practical consideration when designing and constructing an imagery intervention. These are Physical, Environment, Task, Timing. Learning, Emotion and Perspective (see Holmes & Collins, 2002, for a detailed review). Whilst it is not essential, and indeed not always advised, to incorporate all of these considerations at once, several studies have demonstrated the effectiveness of PETTLEP imagery compared to more traditional imagery techniques focusing primarily on visual imagery and often conducted in a seated or lying position (e.g., Smith, Wright, Allsopp & Westhead, 2007; Wright & Smith, 2007). PETTLEP-based imagery has also been shown to improve performance of strength tasks (Lebon, Collet & Guillot, 2010; Wakefield & Smith, 2011; Wright & Smith, 2009).

Like imagery, a large body of literature exists supporting efficacy of action observation for improving performance in a variety of motor skills (Ste-Marie, Law, Rymal, O, Hall, & McCullagh, 2012), including strength-based tasks (Ram, Riggs, Skaling, Landers, & McCullagh, 2007). Action observation is defined as observing others to create an internal representation of perceived actions (Gallese, 2001). Several investigators have shown that imagery and action observation both activate the motor regions of the brain in a similar manner (Grèzes & Decety, 2001; Munzert, Zentgraf, & Vaitl, 2008) and brain mapping studies have shown that similar neural areas are activated during the physical execution or imaged/observed mental simulation of motor actions (Filimon, Nelson, Hagler, & Sereno, 2007; Grèzes & Decety, 2001; Hardwick, Caspers, Eickhoff, & Swinnen, 2018).

More recently, researchers have begun to focus on the effects of engaging in imagery and action observation simultaneously on activity in the motor system (see Eaves, Riach, Holmes, & Wright, 2016 and Vogt, Di Rienzo, Collet, Collins, & Guillot, 2013 for reviews). This research indicates that the simultaneous combination of imagery and action observation is associated with increased activity in motor regions of the brain, compared to the single use of either technique (e.g., Sakamoto, Muraoka, Mizuguchi, & Kanosue, 2009; Villiger et al., 2013; Wright, Williams, & Holmes, 2014). As such, researchers have recently argued that combined imagery and action observation interventions may be more effective for improving sport performance, compared to the independent use of either technique (Holmes & Wright, 2017). To date, however, little evidence exists to support the efficacy of combined imagery and action observation interventions in enhancing motor skill performance.

One area where combined imagery and action observation interventions may prove particularly beneficial is in improving strength performance. Wright and Smith (2009) and Scott, Taylor, Chesterton, Vogt, and Eaves (2017) have shown the potential benefits of combined imagery and action observation for improving strength performance in group-based study designs. However, such designs can mask important individual differences in response to interventions. Therefore, it would be useful to explore whether imagery can produce measurable changes in muscle strength in such a way that individual differences in responses can be easily examined (i.e., using a single-case design). Such an idiographic approach would enable a close examination of the effects of an imagery and action observation intervention on individuals. Given that there may be considerable interindividual differences in responses to such interventions, averaging the results for individuals will effectively ignore the effects of the intervention on the individuals. Thus, in line with recent arguments made in the applied sport psychology literature (Barker, Mellalieu, McCarthy, Jones and Moran, 2013), we argue that there is a need for more single-case designs in research examining the effects of sport psychology interventions.

Accordingly, the aim of this study was to use a single-case design to examine whether a PETTLEP-based, combined imagery and action observation intervention improved bicep strength compared to imagery without observation and baseline conditions. Based on previous findings (Wright & Smith, 2009), we hypothesized that performance increases would be observed in the intervention period, compared to baseline. A second hypothesis, based on evidence that combined imagery and observation of a strength task produces increased corticospinal excitability (Sakamoto et al., 2009) and improvements in strength (Scott et al., 2017) was that the imagery intervention performed with the observational aid would result in greater strength gains than the imagery intervention alone.

Method

Participants

Four male participants (*mean age* = 24.0 years, *SD* = 3.54) were recruited from a postgraduate population at a UK university. Potential participants were questioned on current and previous weight training experience and only those who were not currently engaged in a weight-training program were included.

Measures

Movement Imagery Questionnaire 3 (MIQ-3; Williams et al., 2012). The MIQ-3 is a 12-item inventory that assesses an individual's capability to perform internal visual, external visual, and internal kinesthetic imagery of four movements: A knee lift, jump, arm movement and toe touch. As per the questionnaire instructions, participants physically performed each of the requested actions a single time. Following execution of the action, participants were instructed to image the movement, using an internal visual, external visual, or kinesthetic modality. Participants then rated the ease or difficulty with which they completed the imagery on a 7-point Likert type scale ranging from 1 (*very hard to see/feel*) to 7 (*very easy to see/feel*). The predictive validity of MIQ-3 has been demonstrated by Williams et al. (2012), who showed a strong relationship between MIQ-3 scores and observational learning use.

Imagery diary. Participants were provided with an imagery diary, which they were encouraged to complete after each imagery session to confirm that they had performed their imagery. They were instructed to note down the date and time of their imagery session, and any difficulties they experienced while performing their imagery, as well as any deviations from normal patterns, such as amount of sleep and any heavy lifting completed.

Equipment

Bicep curl machine. A bicep curl machine (Techno Gym Arm Curl) was used. The resistance varied from 5kg to 68.75kg with 1.25kg increments. Participants received instructions on good technique as well as a demonstration before the start of each baseline testing session from a qualified instructor experienced with using this machine. This was to ensure their safety and to encourage consistency with their technique so that each testing session was performed in a similar manner.

Design

The performance measure used was a one repetition maximum (1 R.M.) lift on the bicep curl machine. A baseline design of three collection points was used, as previous research (White, 1974) indicated that this was the minimum required to produce a baseline with sufficient stability. Each intervention was then administered for four weeks, in a counterbalanced manner, with 1 R.M. performance being completed at the end of each week during the baseline and intervention phases (resulting in a total of 11 measures being performed by each participant, see Table 1). Previous imagery studies have found improved strength resulting from as few as two weeks of imagery practice (Shackell & Standing, 2007), and the total number of imagery sessions in the present study mirrored that of Wright and Smith's (2009) study, which found an increase in 1 R.M. strength using imagery alone.

Procedure

Following institutional ethical approval, and prior to commencement of the study, all participants provided written informed consent after being given information on the purpose of the study and its requirements. Participants then completed the MIQ-3, the results of which indicated that all participants had good imagery ability, with each participant displaying high scores for most subscales (see Table 1). Following the first baseline 1 R.M. testing session, participants completed a set of 6-10 repetitions to failure on the bicep curl machine in order to produce the observation video. Here, an individualized video of these repetitions was taken from above for each participant; an angle used to simulate an internal visual perspective (see

Figure 1). This video also included typical noises from the gym, including talking and background music.

After completing the three-week baseline period, participants received PETTLEP imagery instructions and training. Firstly, response training (Lang, Kozak, Miller, Levin, & McLean, 1980) was carried out. Each participant started this by generating a simple image of himself sitting at the bicep curl machine in the gym, with attention being drawn to aspects of the imaged scenario that he found relatively easy to image. Additional details relevant to the scenario were then progressively added according to the responses of the participant (e.g., different sensory modalities, physiological and emotional responses). This continued until a complete and vivid imagery experience was produced that the participant stated he was happy with. The completed script was then used by the participant to practice imaging, which allowed any details he felt were missed first time round to be included, as well as allowing the altering of elements such as the wording to make the script as personalized and easy to read as possible. An example script was as follows:

"You are about to perform a set of repetitions to failure on the bicep curl machine. Prior to sitting in the machine you gradually clear your mind of all other concerns, ignoring the other gym-goers and the music blaring in the background. Instead, you focus on the task ahead of you, pushing your biceps to the limit. When you're ready you adjust the seat height and then place the pin in the weight stack, noting that you are about to set a personal best. You start to feel your heart pump faster already and you feel your palms become sweaty in anticipation. You feel excited but a little nervous as you think about lifting more weight than you have ever done before. You sit in the machine and grasp the handles, feeling the knurled surface rub against your skin. You start to slowly curl the handles towards you and feel your biceps stiffen as the handles come up, with a feeling of triumph as you realise you can easily handle this weight. You then slowly lower the handles and hear the soft 'clunk' as the weight descends on the stack. You perform each repetition slowly and smoothly, and your biceps begin to burn but you keep lifting as you are determined to do more repetitions than ever before. Your heart is now pounding and your biceps are burning, but you slowly grind that weight upwards for another repetition. On the next repetition your biceps are on fire, you are really feeling the burn but will not give up! You pull that weight up as if your life depended on it, you can feel sweat stinging your eyes and your heart feels like it is going to burst out of your chest, but you keep going. Finally, you try to lift the weight and no matter how hard you try, the handles will not budge an inch. Your whole body is shaking now as you try to get that one last repetition, and you feel the cold sensation of the sweat rolling down your skin and your biceps now feel like an inferno. Knowing that you have given 100% and couldn't do any more, you get a great feeling of satisfaction as you let go of the handles. You notice the great pump on your biceps as they are filled blood: another personal best!"

Participants were asked to complete imagery from a first person perspective, to reflect that of the video and replicate the pre- and post-test performance perspective. Using first person visual perspective imagery mirrored the Wakefield and Smith (2011) and Wright and Smith (2009) studies, which both showed improved bicep curl strength.

All aspects of the PETTLEP model of imagery were addressed through the interventions.

Physical: For the physical component, participants were instructed to mentally simulate the kinesthetic sensations experienced when performing a bicep curl. Participants were instructed to sit on a chair with their arms down by their sides, while holding onto cylindrical objects similar in diameter to the bicep curl machine handles, a technique previously suggested by Holmes and Collins (2001). In addition, participants wore clothing similar to that worn when performing their actual 1 R.M. tests (i.e., if they wore a t-shirt in the test then they also wore a t-shirt when performing the imagery).

Environment: Whether imagery training is conducted in the performance environment or not has varied in previous studies using PETTLEP imagery. However, because previous studies (i.e., Wakefield & Smith, 2011) found promising results with PETTLEP imagery performed at home, it was decided to replicate this procedure. Nevertheless, efforts were made to keep the imagery PETTLEP-centered, including the environment element of the model. Participants were encouraged to concentrate on their physical and psychological responses to the training situation and relevant stimuli from the gym environment (for example lighting and temperature) and these were included in the imagery scripts and associated videos.

Task: The task element of PETTLEP imagery centered on imaging bicep curls on the machine to emulate the performance measure as closely as possible, and ensuring the appropriate attentional focus. Response training concentrated on each participant's attention during the performance of the baseline bicep curls, which allowed the scripts to be individualized as per appropriate skill level and attentional focus of each participant. For example, one participant might concentrate on gripping the handles of the machine and moving the weight while another might be concentrating more on feeling the contraction of the bicep muscles, depending on his level of experience and personal preference.

Timing: Participants were encouraged to perform imagery in 'real time' with the cadence set at a 1-second concentric and 3-second eccentric muscle action. In the video-absent intervention block, participants were instructed to try to recall the speed at which they performed their repetitions to failure in the baseline testing phase. In the intervention block where the observational video was used, timing of the imagery mirrored that seen in the individual videos.

Learning: The learning element was addressed by requiring the participants to go over their imagery scripts again after completion of the first intervention block. Olsson and Nyberg (2010) discussed the importance of physical experience as a factor that could influence imagery ability, therefore the imagery scripts were created after the final baseline-testing phase, allowing participants time to become accustomed to the bicep curl movement. Without this period of acclimatization to the physical movement, after only a few sessions the content of their imagery scripts may have needed to drastically change to stay relevant to the participants' experience and skill level.

Emotion: Response training was used to engage the emotional component of the model, by recording emotional responses during the baseline testing phase and encouraging participants to include these emotions in their imagery practice. For example, one participant recorded that he felt satisfaction after completing his last repetition, whilst another felt relieved. These, and other similar positive emotions, were included in the imagery scripts.

Perspective: In the video intervention block, the perspective element was addressed by the first person perspective displayed on the video, which showed participants performing bicep curls of their repetitions to failure recorded in the baseline testing phase. This visual perspective was chosen as it has been reported to be more effective for improving strength performance than imagery from third person visual perspectives (Slimani et al., 2016). In the video-absent intervention block, participants noted down visual cues from their baseline testing phase, and were encouraged to concentrate on these visual cues when performing their imagery training. These visual cues included details external to the participant such as gym equipment in view of the participant as well as seeing the movement of hands and arms during execution of the bicep curl.

Over the 8 weeks of the interventions, participants imaged themselves performing two sets of 6-10 repetitions to failure either with or without the observational video, depending on the intervention. Participants were required to perform each intervention three times a week for four weeks, before commencing the next intervention phase, in a counterbalanced order. Participants performed a 1 R.M. at the end of each week to monitor weekly progress. As previously indicated, participants' imagery diaries also served as manipulation checks, ensuring that participants had correctly performed their imagery as well as discussing deviations from normal behaviors such as sleeping patterns and physical exertion. Details of any issues or difficulties with following the imagery interventions were also noted. In the event, all participants completed the diaries as instructed. These showed that the participants reported completing their imagery as instructed, and no difficulties, or confounding factors such as great physical exertion, were noted.

Data Analysis

The data from the participants' individual 1 R.M. scores were plotted onto a graph. Visual inspection is a commonly used form of analysis in single-case designs (Kinugasa, Cerin, & Hooper, 2004). However, in order to produce a more robust analysis, lines representing the mean for the baseline, total intervention and each intervention phase, in addition to trend lines, were added. To further extend the analysis, binomial statistics were carried out. These tests involve calculations of the number of data points above and below trend lines in order to establish any significant differences, and were conducted in line with previous single-case design studies (Callow, Hardy, & Hall, 2001; Wakefield & Smith, 2011). Furthermore, effect sizes were calculated using the formula proposed by Kromrey and Foster-Johnson (1996), and previously used in single case study designs of a similar nature. Based upon previous data, Parker and Vannest (2009) examined effect sizes for single-case designs and proposed that an effect size of <.87 is small, .87-2.67 is medium and >2.67 is large.

Results

Participant 1 – Performance Data

Participant 1's mean score in the baseline phase was 45.83 kg (SD = 1.61), with a gradient of x.83. This increased to 53.13 kg (SD = 1.61, gradient x.19) in the first intervention phase (imagery + video), and remained at 53.13 kg (SD = 1.61, gradient x-.75) in the second intervention phase (imagery). The mean score for the overall intervention phases combined was 53.13 kg (SD = 1.49), an increase of 16.36% from the baseline measure. The scores recorded each week as well as the phase means can been seen in Figure 2. The black dots joined by thick black lines represent the weekly 1 R.M. scores, with the thin grey lines in each segment representing the mean for each phase. Binomial tests showed a significant increase in 1 R.M. strength when comparing the overall post intervention data with the projected baseline data ($p < .001$). However, no significant differences were apparent when comparing the second intervention (imagery) to the projected first intervention (imagery + video) data ($p > .05$). Effect sizes were calculated, comparing mean data from the baseline and intervention periods. These were 6.19 and 6.72 from baseline to the imagery with video intervention phase, and to the imagery intervention phase respectively. There was an effect size of .45 from the imagery with video intervention phase to the imagery intervention phase. The effect size from baseline to the combination mean of both intervention phases was 6.36.

Participant 2 – Performance Data

Participant 2's mean score in the baseline condition was 48.75 kg (SD = 1.02), with a gradient of x.83. This increased to 53.44 kg (SD = 1.62, gradient x.42) in the first intervention phase (imagery), followed by 57.94 kg (SD= 1.23, gradient x.59) in the second intervention phase (imagery with video). The mean score for the overall intervention phase was 55.69 kg (SD = 2.67), an increase of 14.24% from the baseline measure (see Figure 3). Binomial tests showed a significant increase in 1 R.M. strength when comparing the overall post-intervention data with the projected baseline data ($p < .001$). However, no significant differences were apparent when comparing the second intervention (imagery + video) to the projected first intervention (imagery) data ($p > .05$). Effect sizes were calculated comparing mean data from the baseline and intervention periods. These were 4.59 and 9.00 from baseline to the imagery intervention phase and to the imagery with video intervention phase, respectively. There was an effect size of 2.78 from the imagery intervention phase to the imagery with video intervention phase. The effect size from baseline to the combination mean of both intervention phases was 6.80.

Participant 3 – Performance Data

Participant 3's mean score in the baseline phase was 43.08 kg (SD = 2.79), with a gradient of x2.25. This increased to 51.25 kg (SD = .88, gradient x.19) in the first intervention phase (imagery + video), followed by 54.06 kg (SD = 1.62, gradient x.83) in the second intervention phase (imagery). The mean score from the two intervention phases combined was 52.66 kg (SD = 1.92), an increase of 22.24% from the baseline measure (see Figure 4). Binomial tests showed no significant increase in 1 R.M. strength when comparing the overall post intervention data with the projected baseline ($p > .05$). However, a significant increase was apparent in bicep strength in the imagery phase, compared to the projected imagery with video data ($p < .05$). Effect sizes were calculated comparing mean data from the baseline and intervention periods. These were 2.93 and 3.94 from baseline to the imagery with video intervention phase and the imagery intervention phase respectively. There was an effect size of 3.18 from the imagery with video phase to the imagery phase. The effect size from baseline to the combination mean of both intervention phases was 3.44.

Participant 4 – Performance Data

Participant 4's mean score in the baseline phase was 36.25 kg (SD = 1.02), with a gradient of x.42. This increased to 39.17 kg (SD = .59, gradient x.00) in the first intervention phase (imagery), followed by 42.5 kg (SD = .88, gradient x.45) in the second intervention phase (imagery + video). The mean score from the two intervention phases combined was 41.07 kg (SD = 1.82), an increase of 13.3% from the baseline measure (see Figure 5). Binomial tests showed a significant increase in 1 R.M. strength when comparing the overall post intervention data with the projected baseline ($p < .001$). However, no significant differences were apparent when comparing the second intervention (imagery + video) to the projected first intervention (imagery) data ($p > .05$). Effect sizes were calculated comparing mean data from the baseline and intervention periods. These were 2.86 and 6.12 from baseline to the imagery intervention phase and the imagery with video intervention phase respectively, with an effect size of 5.66 from the imagery intervention phase to the imagery with video intervention phase. The effect size from baseline to the combination mean of both intervention phases was 4.72.

Discussion

The results of the current study are in line with the first hypothesis as all participants showed an improvement in bicep strength from baseline to the intervention phase. This finding is supported by previous literature on the topic, as several studies have shown imagery to be an effective technique in enhancing strength performance (Lebon et al., 2010; Wakefield & Smith, 2012; Wright & Smith, 2009; see Slimani et al., 2016 for a review). Within single case design work, Barker, McCarthy, Jones and Moran (2011) explain that the number of times a result can be replicated the more likely it is to be accurate. Furthermore, the fewer overlapping data points between baseline and intervention phases, the higher the confidence we can have that an effect has occurred (Barker et al., 2011). Three out of four participants showed an improvement in bicep strength following the intervention phases, and across all participants, no data points in the intervention phases overlapped with that participant's baseline data points. These findings therefore provide an indication that bicep strength improved because of the imagery interventions.

The neural mechanisms mentioned in the introduction may explain how PETTLEP imagery enhanced 1R.M. performance. There is clear widespread activity of brain areas associated with both motor imagery and action execution that overlap extensively with one another (Grèzes & Decety, 2001; Hardwick, Caspers, Eickhoff, & Swimmen, 2018) to create a superior performance. The subsequent facilitation of corticospinal excitability may also be reflective of activity in the pre motor brain regions that connect to the primary motor cortex (Fourkas, Bonavolontà, Avenanti, & Aglioti, 2008; Wright et al., 2014), derived from the disturbance of the spinal motor neuron pool. This may result in enhanced performance as a result of imagery interventions, providing a potential explanation of our findings. However, we cannot confirm this from the current data, and thus future research combining imagery of strength tasks and psychophysiological measures would be a welcome addition to the literature.

The significant differences apparent were in improvements from baseline to the overall intervention period. Within this, in three of the four cases, there were no significant differences in the efficacy of PETTLEP imagery and observation, compared to PETTLEP imagery alone. These findings appear to conflict with the second hypothesis and suggest that both conditions produced an efficacious effect on performance following a 4-week intervention period. Whilst this finding is unexpected given previous research on the topic (e.g., Scott et al., 2017), it is important to note that the weight lifted did increase for the two participants who were assigned the combination of observation and imagery in the second intervention phase, and there were positive performance trajectories in all cases for the combination intervention. In contrast, in the two cases where the imagery intervention in isolation formed the second intervention phase, it did not change the performance trajectory. This suggests that imagery in isolation had a performance maintenance, rather than performance enhancing, effect. Therefore, had we adopted a purely visual analysis, as is common in single-case research, we would have concluded that our results unequivocally supported the dual use of combined imagery and action observation. The statistical analyses employed here set the bar high in terms of the burden of evidence, given the low number of data points and an n of 1. Thus, we should not dismiss entirely the possible usefulness of the combined interventions. Rather, we would argue that our findings suggest that consultants should offer athletes the opportunity to exercise a preference for utilizing an additional observation aid when engaging in imagery interventions for performance enhancement. That is, inclusion of an observational aid does not appear to be always essential for maximizing strength gains from imagery, but neither would it reduce the effectiveness of the intervention. This is crucial given the importance of the individualizing of imagery scripts and practices for optimal results (Smith, Holmes, Collins, Whitemore, & Devonport, 2001; Wilson, Smith, Burden, & Holmes, 2010).

The mean and trend results also indicate that the second intervention phase that the participants completed was equally or more efficacious than the first, regardless of the ordering of the interventions. Previous research has shown that physiological adaptations have the potential to occur over a longer period than used in the present study. For example, Wakefield and Smith (2011) found strength increases still occurring after 15 weeks of interventions using imagery without physical practice. It is possible, therefore, that it was irrelevant which imagery condition was being used, as both continued to improve bicep strength performance. The participants who completed the combined intervention second demonstrated a further increase in performance because of the added observational aid. However, lesser effects were seen for the imagery intervention in the cases where this intervention was completed following the combined intervention. There is also the potential that participants completing the combined intervention phase first may have experienced a continued performance effect when completing the imagery-only intervention (e.g., remembering more information about timing and environment). Furthermore, owing to the untrained nature of the participant group, it is possible that strength changes may have been amplified owing to the weekly 1 R.M test conducted. Whilst this did not occur in previous studies that employed a similar design (e.g., Wakefield & Smith, 2011), it remains a possibility. Future research should examine this with a trained population which would likely be more consistent in baseline performance and therefore more resilient to the effects of a weekly 1 R.M.

In the current study the effect sizes for each participant, from the baseline mean to the combined intervention mean, ranged from 3.44 to 6.80, signifying a large effect on 1 R.M. performance caused by the introduction of the intervention phases. This supports the predictions of the first hypothesis, and additionally these results resemble those of previous research, which have shown that PETTLEP imagery can be an effective method of improving strength performance (Wright & Smith, 2009; Wakefield & Smith, 2011). Although treatments did not show significant differences between PETTLEP imagery alone and PETTLEP imagery combined with observation, the effect sizes exhibit intriguing results; these indicate that there were discrepancies between interventions when compared to the baseline measure. For example, participant 2 displayed an effect size of 9.00 for the imagery and observation intervention and 4.59 for the PETTLEP imagery intervention. These results are interesting, as Wright and Smith (2009) also observed comparable effect sizes in their study. This again highlights the requirement for additional research examining the efficacy of PETTLEP imagery, action observation and combined interventions on performance.

In conclusion, the results offer further support to previous studies regarding the use of the PETTLEP model as a framework when constructing imagery interventions in order to improve strength performance (Wakefield & Smith, 2011; Wright & Smith, 2009). Whilst the statistical analyses in the present study did not confirm that the addition of an observational aid significantly improved the effectiveness of the imagery interventions, visual analyses did suggest that it may improve the rate of strength gains when compared to PETTLEP imagery alone. Regardless of whether an observational aid has a ‘direct hit’ effect on performance, it appears that the use of observation during imagery can certainly help to provide a strong PETTLEP basis to the intervention, most notably the environment, timing and perspective aspects; this is particularly so when it is impractical for participants to perform imagery in the performance environment. The results of this study have important implications for imagery use and optimizing strength training benefits. When devising imagery interventions, coaches and athletes should provide detailed PETTLEP-based instructions, specifically those outlined within the current literature (e.g., Wakefield & Smith 2012). Evidence from both this study and the emerging literature suggest that the combination of PETTLEP imagery and action observation can result in substantial performance increases, as can PETTLEP imagery alone. As such, applied practitioners working with athletes and exercisers to improve strength performance are encouraged to use PETTLEP-based imagery interventions to contribute towards improvements in strength, and practitioners should be aware that use of a video-based observational aid alongside the imagery might assist in this process. This may be particularly helpful when delivering imagery interventions with individuals with low imagery ability. A randomized controlled trial comparing the effectiveness of PETTLEP with and without action observation would be a very useful addition to the imagery and strength literature.

These findings also illustrate the large interindividual variations in the effects of imagery and observation interventions, emphasizing the importance of practitioners carefully considering individual differences in response to these. Imagery was very effective for all participants, but although action observation was less consistently so, participant 2 and 4's effect size data suggest considerable improvement from the addition of this to the imagery intervention. Therefore, trying to implement interventions based on the results of group-based studies can be problematic, and we would strongly recommend treating the results of such studies with caution when implementing imagery interventions, assessing carefully the individual's responses. In addition, action observation should not be an automatic addition to imagery interventions as for some individuals it does not seem to add to imagery's effectiveness. However, if the individual has a preference to use an observational aid to accompany their imagery then the inclusion of an observational aid will not be detrimental to the efficacy of the intervention.

References

Barker, J., McCarthy, P., Jones, M., & Moran, A. (2011). *Single-Case Research Methods in Sport ad Exercise Psychology*. London: Routledge.

Barker, J., Mellalieu, S., McCarthy, P. J., Jones, M. V., & Moran, A. (2013). Special issue n single-case research in sport psychology. *Journal of Applied Sport Psychology*, *25*, 1-3. https://doi.org/10.1080/10413200.2012.729378.

Callow, N., Hardy, L., & Hall, C. (2001). The effects of a motivational general-mastery imagery intervention on the sport confidence of high-level badminton players.

Research Quarterly for Exercise and Sport, *72*(4), 389–400. https://doi.org/10.1080/02701367.2001.10608975.

Eaves, D. L., Riach, M., Holmes, P. S., & Wright, D. J. (2016). Motor imagery during action observation: a brief review of evidence, theory and future research opportunities. *Frontiers in Neuroscience, 10*. https://doi.org/10.3389/fnins.2016.00514

Filimon, F., Nelson, J. D., Hagler, D. J., & Sereno, M. I. (2007). Human cortical representations for reaching: mirror neurons for execution, observation, and imagery. *NeuroImage, 37*(4), 1315–1328. https://doi.org/10.1016/j.neuroimage.2007.06.008

Fourkas, A. D., Bonavolontà, V., Avenanti, A., & Aglioti, S. M. (2008). Kinesthetic imagery and tool-specific modulation of corticospinal representations in expert tennis players. *Cerebral Cortex*, *18*(10), 2382–2390. https://doi.org/10.1093/cercor/bhn005

Grèzes, J., & Decety, J. (2001). Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Human Brain Mapping*, *12*(1), 1–19.

Hardwick, R. M., Caspers, S., Eickhoff, S. B., & Swinnen, S. P. (2018). Neural correlates of action: Comparing meta-analyses of imagery, observation and execution. *Neuroscience & Biobehavioral Reviews, 94,* 31-44. https://doi.org/10.1016/j.neubiorev.2018.08.003Holmes, P. S., & Collins, D. J. (2001). The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists. *Journal of Applied Sport Psychology*, *13*(1), 60–83. https://doi.org/10.1080/10413200109339004

Holmes, P. S., & Collins, D. J. (2002). Functional equivalence solutions for problems with motor imagery. In I. Cockerill (Ed) *Solutions in sport psychology*, pp. 120-140, London: Thompson.

Kinugasa, T., Cerin, E., & Hooper, S. (2004). Single-subject research designs and data analysis for assessing elite athletes' conditioning. *Sports Medicine, 34*(15), 1035-1050.

Kromrey, J. D., & Foster-Johnson, L. (1996). Determining the efficacy of intervention: The use of effect sizes for data analysis in single-subject research. *Journal of Experimental Education*, *65*(1), 73–93. https://doi.org/10.1080/00220973.1996.9943464

Lang, P. J., Kozak, M.J., Miller, G.A., Levin, D.N., & McLean, A. (1980). Emotional imagery: Conceptual structure and pattern of somato-visceral response. *Psychophysiology*, *17,* 179–192.

Lebon, F., Collet, C., & Guillot, A. (2010). Benefits of motor imagery training on muscle strength. *Journal of Strength and Conditioning Research*, *24*(6), 1680–1687. https://doi.org/10.1519/JSC.0b013e3181d8e936

Munzert, J., Zentgraf, K., Stark, R., & Vaitl, D. (2008). Neural activation in cognitive motor processes: comparing motor imagery and observation of gymnastic movements. *Experimental Brain Research 188*, 437-444. https://doi.org/10.1007/s00221-009-1376-y

Mulder, T. (2007). Motor imagery and action observation: cognitive tools for rehabilitation. *Journal of Neural Transmission*, *114*(10), 1265–1278. https://doi.org/10.1007/s00702-007-0763-z

Olsson, C.-J., & Nyberg, L. (2010). Motor imagery: if you can’t do it, you won’t think it. *Scandinavian Journal of Medicine & Science in Sports*, *20*(5), 711–715. https://doi.org/10.1111/j.1600-0838.2010.01101.x

Parker, R. I., & Vannest, K. (2009). An improved effect size for single-case research: nonoverlap of all pairs. *Behavior Therapy*, *40*(4), 357–367. https://doi.org/10.1016/j.beth.2008.10.006

Ram, N., Riggs, S. M., Skaling, S., Landers, D. M., & McCullagh, P. (2007). A comparison of modelling and imagery in the acquisition and retention of motor skills. *Journal of Sports Sciences*, *25*, 587-597. https://doi.org/10.1080/02640410600947132

Sakamoto, M., Muraoka, T., Mizuguchi, N., & Kanosue, K. (2009). Combining observation and imagery of an action enhances human corticospinal excitability. *Neuroscience Research*, *65*(1), 23–27. https://doi.org/10.1016/j.neures.2009.05.003

Scott, M., Taylor, S., Chesterton, P., Vogt, S., & Eaves, D. L. (2017). Motor imagery during action observation increases eccentric hamstring force: an acute non-physical intervention. *Disability and Rehabilitation*, 1–9. https://doi.org/10.1080/09638288.2017.1300333

Shackell, E. M., and Standing, L. G. (2007). Mind over matter: mental training increases physical strength. *North American Journal of Psychology*, *9*(1), 189-200.

Slimani, M., Tod, D., Chaabene, H., Miarka, B., & Charmari, K. (2016). Effects of mental imagery on muscular strength in healthy and patient participants: A systematic review. *Journal of Sports Science & Medicine, 15*(3), 434-450.

Smith, D., Holmes, P., Collins, Whitemore, L., & Devonport, T. (2001). The effect of stimulus and response-laden imagery scripts on field hockey performance. *Journal of Sport Behavior, 23*, 408-419.

Smith, D., Wright, C. J., & Cantwell, C. (2008). Beating the bunker: the effect of PETTLEP imagery on golf bunker shot performance. *Research Quarterly for Exercise and Sport*, *79*(3), 385–391. https://doi.org/10.1080/02701367.2008.10599502

Smith, D., Wright, C., Allsopp, A., & Westhead, H. (2007). It's All in the Mind: PETTLEP-Based Imagery and Sports Performance. *Journal of Applied Sport Psychology*, *19*(1), 80–92. https://doi.org/10.1080/10413200600944132

Ste-Marie, D. M., Law, B., Rymal, A. M., Jenny, O., Hall, C., & McCullagh, P. (2012). Observation interventions for motor skill learning and performance: an applied model for the use of observation. *International Review of Sport and Exercise Psychology*, *5*(2), 145–176. https://doi.org/10.1080/1750984X.2012.665076

Villiger, M., Estévez, N., Hepp-Reymond, M.-C., Kiper, D., Kollias, S. S., Eng, K., & Hotz-Boendermaker, S. (2013). Enhanced activation of motor execution networks using action observation combined with imagination of lower limb movements. *PloS One*, *8*(8), e72403. https://doi.org/10.1371/journal.pone.0072403.

Vogt, S., Di Rienzo, F., Collet, C., Collins, A., & Guillot, A. (2013). Multiple roles of motor imagery during action observation. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00807

Wakefield, C., & Smith, D. (2011). From strength to strength: a single-case design study of

PETTLEP imagery frequency. *The Sport Psychologist, 25,* 305-320.

Wakefield, C., & Smith, D. (2012). Perfecting practice: applying the PETTLEP model of motor imagery. *Journal of Sport Psychology in Action*, *3*(1), 1–11.

White, O.R. (1974). The "split middle": A "quickie" method for trend estimation. University of Washington, Experimental Education Unit, Child Development and Mental Retardation Center. Seattle, WA.

Williams, S. E., Cumming, J., Ntoumanis, N., Nordin-Bates, S. M., Ramsey, R., & Hall, C. (2012). Further validation and development of the Movement Imagery Questionnaire. *Journal of Sport & Exercise Psychology, 34*, 621-646.

Wilson, C., Smith, D., Burden, A., & Holmes, P. (2010). Participant-generated imagery scripts produce greater EMG activity and imagery ability. *European Journal of Sport Science*, *10*(6), 417–425. https://doi.org/10.1080/17461391003770491

Wright, C. J., & Smith, D. K. (2007). The effect of a short-term PETTLEP imagery intervention on a cognitive task. *Journal of Imagery Research in Sport and Physical Activity*, *2*(1). https://doi.org/10.2202/1932-0191.1014

Wright, C. J., & Smith, D. (2009). The effect of PETTLEP imagery on strength performance. *International Journal of Sport and Exercise Psychology*, *7*(1), 18–31. https://doi.org/10.1080/1612197X.2009.9671890

Wright, D. J., Williams, J., & Holmes, P. S. (2014). Combined action observation and imagery facilitates corticospinal excitability. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00951

Yue, G., & Cole, K. J. (1992). Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. Journal of

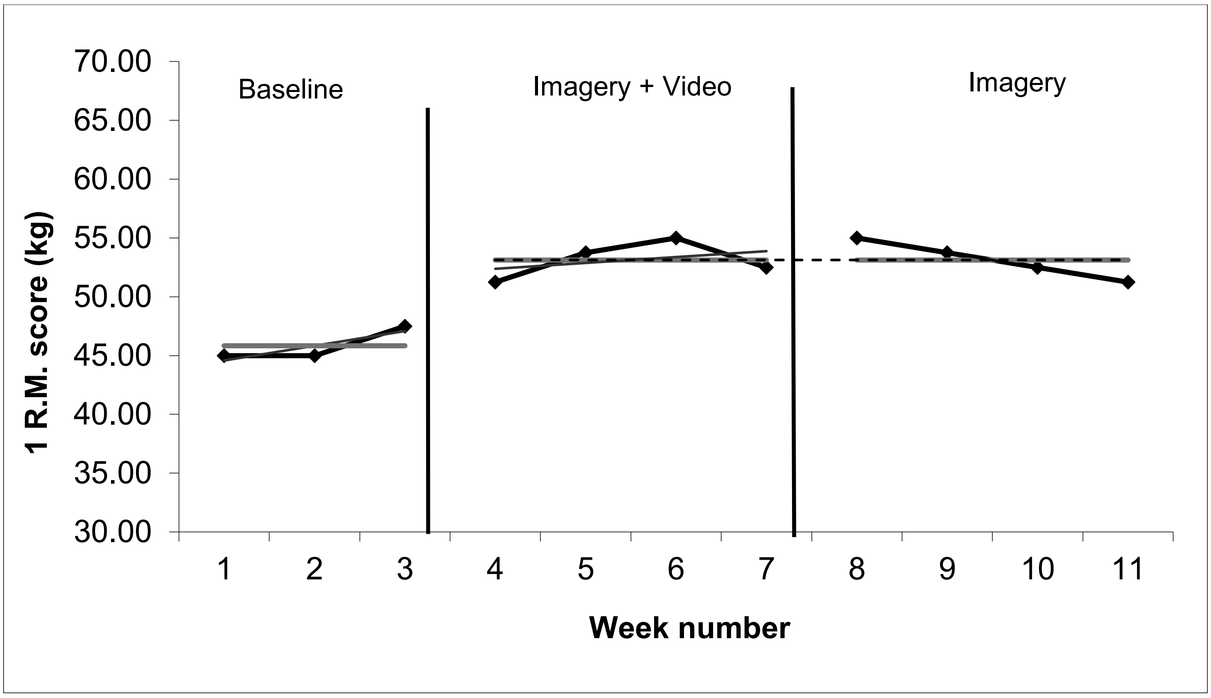
Neurophysiology, 67(5), 1114–1123.

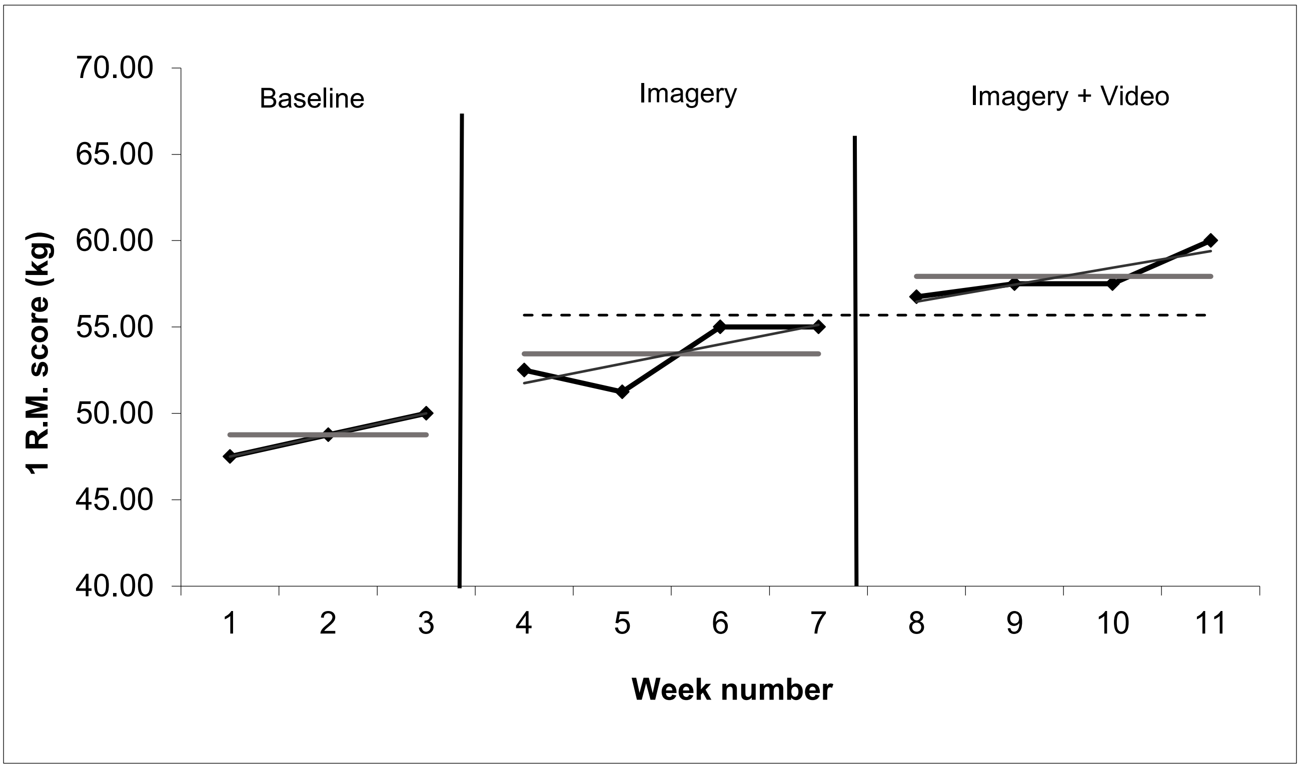
Tables and Figures

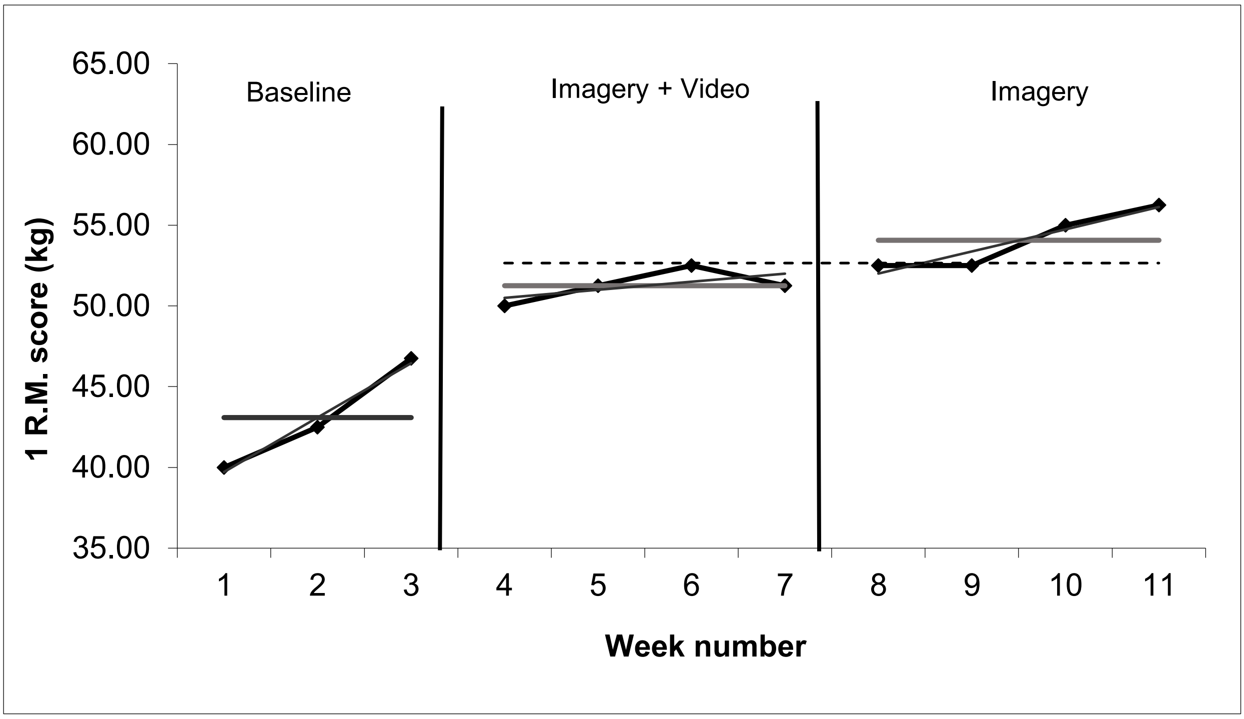
Figure 4 – Bicep curl 1 R.M. scores for Participant 3

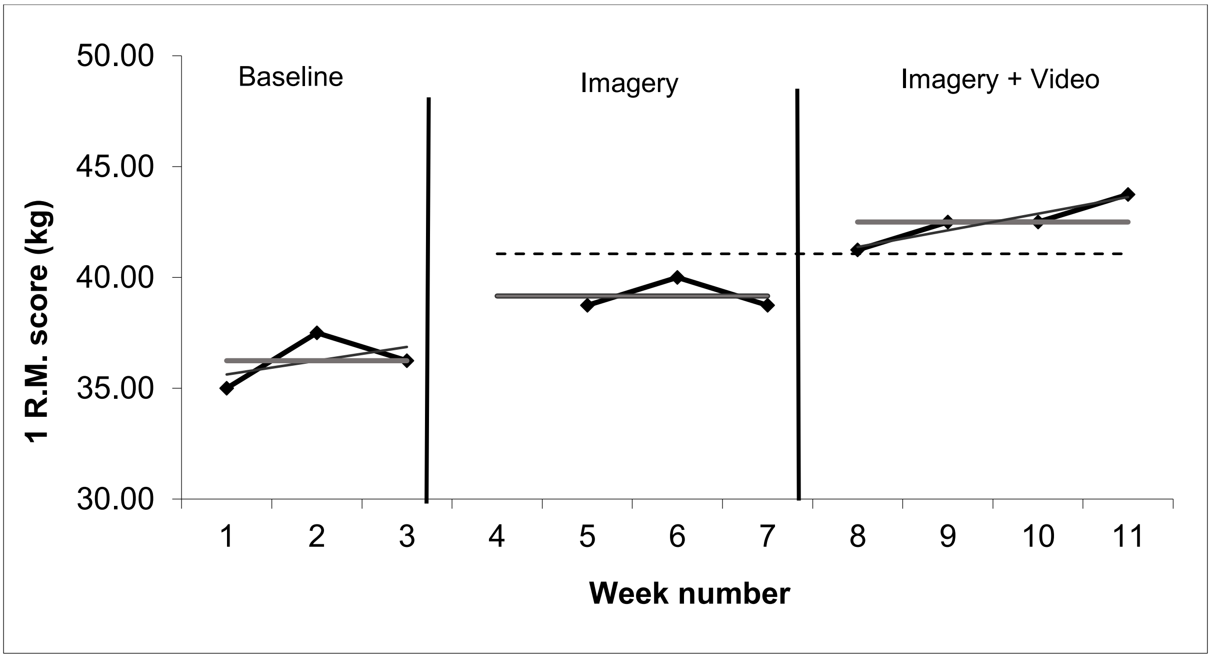
Figure 5 – Bicep curl 1 R.M. scores for Participant 4

	Participant 1	Participant 2	Participant 3	Participant 4
3 weeks	Baseline	Baseline	Baseline	Baseline
4 weeks	Imagery plus Video	Imagery	Imagery plus Video	Imagery
4 weeks	Imagery	Imagery plus Video	Imagery	Imagery plus Video
MIQ-3 Internal	6	6.75	6.5	4
MIQ-3 External	6.25	6.75	6.75	5
MIQ-3 Kinaesthetic	6.25	6.5	4.75	3.75


Baseline
Imagery + Video
Imagery
1 R.M. score (kg)
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
1
2
3
4
5
6
7
8
9
10
11
Week number


70.00
65.00
60.00
55.00
50.00
45.00
40.00
1 R.M. score (kg)
Baseline
Imagery
Imagery + Video
1
2
3
4
5
6
7
8
9
10
11
Week number


65.00
60.00
55.00
50.00
45.00
40.00
35.00
1 R.M. score (kg)
Baseline
Imagery + Video
Imagery
1
2
3
4
5
6
7
8
9
10
11
Week number


Baseline
Imagery
Imagery + Video
50.00
45.00
40.00
35.00
30.00
1 R.M. score (kg)
1
2
3
4
5
6
7
8
9
10
11
Week number