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The Effect of Back Squat Depth and Load on Lower Body Muscle Activity in Group Exercise Participants

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Abstract

Les Mills BODYPUMP^{TM} is a resistance training group exercise class with a low load, high repetition format. Squat training in BODYPUMP^{TM} has two key variables: depth and load. The study aim was to determine the effect of these parameters on the mean and peak EMG amplitude of vastus lateralis, gluteus maximus, biceps femoris and lateral gastrocnemius. 10 female BODYPUMP^{TM} participants (age 41 ± 9 years, height 161.9 ± 3.8 cm, mass 67.7 ± 7.0 kg) performed 1 x 7 squats under four conditions, representing every combination of two depths (90° knee angle and 125° knee angle) and two loads (23% bodyweight and 38% bodyweight). The main effect of depth was significant for mean and peak activity of vastus lateralis and gluteus maximus, and peak activity of biceps femoris and lateral gastrocnemius. The main effect of load was significant for mean and peak activity of gluteus maximus and lateral gastrocnemius. There was no depth * load interaction. These data can be used to inform BODYPUMP^{TM} programme design and amplify the training effect of participation in group exercise classes.

Keywords: Les Mills, resistance training, EMG, motion capture

Word Count: 4821

Introduction

The World Health Organization recommends that adults aged between 18 and 64 years engage in activities that improve muscle strength on at least two days per week (who.int; accessed 21/10/20). Group exercise classes are a relatively low cost and accessible way of achieving physical activity targets, and therefore represent an important opportunity to improve public health. EMD UK, the national governing body for group exercise, reports that 11% of adults in England participate in group exercise on a weekly basis (EMD UK National Survey, 2018). The training outcomes associated with group exercise are therefore increasingly relevant in understanding the practical applications of strength and conditioning research.

Les Mills BODYPUMP^{TM} is a resistance training group exercise class. Each class is 45-60 minutes long and involves using free weights to train all the major muscle groups. The format is low load, high repetition. Sets, repetitions and movement tempo are all pre-choreographed to music. The participants do not normally engage in strength training outside BODYPUMP^{TM} and are predominantly female.

Squatting is included in every BODYPUMP^{TM} class. The mean squat load for a regular BODYPUMP^{TM} participant is 25 ± 8% of their one repetition maximum (1RM) (Harris et al., 2018). The mean number of complete squat repetitions (based on four BODYPUMP^{TM} squat tracks released in 2018-2019) is 99 ± 20. In the context of BODYPUMP^{TM}, the key squat parameters are load and depth. Load is self-selected by the participants. Full squat depth is defined by Les Mills as a 90° knee angle, but in practice, participants vary in the extent to which they maintain this range under fatigue.

The effect of squat load has previously been investigated only in strength-trained participants. Paoli et al. (2009) found that increasing load from 0% (no external load) to 70% of 1RM has no effect on the electromyographic (EMG) activity of vastus lateralis, vastus medialis, rectus femoris, gluteus maximus, gluteus medius, biceps femoris, semitendinosus or adductor magnus. McCaw and Melrose (1999), in contrast, showed that increasing load from 60% to 75% of 1RM increases the activity of vastus lateralis, vastus medialis, rectus femoris and adductor longus but not the activity of gluteus maximus or biceps femoris. Conversely, Yavuz and Erdag (2017) found an increase in vastus medialis and gluteus maximus activity, but not vastus lateralis, rectus femoris, biceps femoris or semitendinosus activity, when they tested muscle activation at 80%, 90% and 100% of 1RM. van den Tillaar et al. (2019) investigated a range of loads between 30% and 100% 1RM and found that in the ascending phase, increasing load leads to a non-linear increase in the activity of vastus lateralis, vastus medialis, rectus femoris, gluteus maximus, biceps femoris and semitendinosus. The majority of evidence therefore suggests that in strength-trained participants, greater load results in greater activity of a subset of hip and knee extensors. However, the reported response of individual muscles is frequently conflicting. Furthermore, these data do not relate to endurance-trained BODYPUMP^{TM} participants, whose neuromuscular response to load may be different to that of strength-trained participants.

The effect of squat depth on muscle activity is not well established. Gorsuch et al. (2013) compared EMG data for 45° knee flexion and 90° knee flexion squats performed using a load equal to depth-specific 10RM (0° knee flexion is neutral standing). EMG activity for rectus femoris, but not biceps femoris or lateral gastrocnemius, was significantly higher in the 90° knee flexion squat than in the 45° knee flexion squat (Gorsuch et al., 2013). The mean load, however, was 78kg and 51kg for the 45° knee flexion and 90° knee flexion squat respectively. This may explain why biceps femoris and lateral gastrocnemius activity in the 90° knee flexion squat was not higher than in the 45° knee flexion squat. Contreras et al. (2016) used EMG to compare muscle activity in parallel (top of the thigh parallel with the floor) and full (maximum knee flexion) squats. No significant difference in mean or peak EMG was observed for vastus lateralis, gluteus maximus or biceps femoris (Contreras et al., 2016). However, the load for each condition was again equal to depth-specific 10RM. The effect of squat depth on muscle activity therefore remains unclear due to the covariation of load.

Current evidence relating to the effect of squat depth on muscle activity is also affected by inconsistent use of maximum voluntary isometric contraction (MVIC) for EMG normalisation. Due to a lack of consensus on how to achieve maximum isometric contraction of vastus lateralis and gluteus maximus, Contreras et al. (2016) used two different MVIC protocols, selected on a per-participant basis. The vastus lateralis activity recorded in the squat testing was greater than that achieved in the MVIC, indicating that neither MVIC protocol resulted in maximum activation (Contreras et al., 2016). Suydam et al. (2017) reported that for vastus lateralis and lateral gastrocnemius, a countermovement jump (CMJ) elicited greater peak EMG values with greater within-participant reliability than the corresponding MVICs, despite the non-elite nature of the participants. Normalisation of squat EMG values using CMJ data may therefore allow reliable analysis of the effect of squat depth on muscle activation in BODYPUMP^{TM} participants.

Squat training is frequently included in group exercise classes such as BODYPUMP^{TM}. However, there is currently no evidence demonstrating the effect of load on muscle activity in non-strength trained participants. The role of squat depth is yet to be investigated in the absence of a confounding load effect. The aim of this study was therefore to establish the effect of squat load and squat depth on the EMG activity of vastus lateralis, gluteus maximus, biceps femoris and lateral gastrocnemius in BODYPUMP^{TM} participants. The hypothesis was that both increased depth and increased load would lead to greater activation of all four muscles.

Methods

Participants

Fourteen female BODYPUMP^{TM} participants were recruited. One withdrew due to injury (unrelated to the study) and two withdrew due to competing personal commitments. Data were not collected for one participant due to equipment failure. 10 participants completed the study. Descriptive data are shown in *Table 1*. Inclusion criteria required that participants were aged between 18 and 55 years, and had participated in at least one BODYPUMP^{TM} class per week for a minimum of 12 weeks. Participants that engaged in strength training outside BODYPUMP^{TM} were excluded. Males were also excluded as their muscle recruitment strategy for squatting may differ from that of females (Hale et al., 2014).

Each participant was informed of the risks and benefits of taking part in exercise testing and was required to provide written, informed consent. Participants were also required to complete a Physical Activity Readiness Questionnaire (PAR-Q) and Medical Screening Questionnaire to determine their suitability for exercise testing. The protocol received ethical approval from The Ethics Committee of Moray House School of Education and Sport (University of Edinburgh).

Procedures

The study had a cross-over design with repeated measures. The order of trials was randomised and partially counterbalanced using a Latin Square.

Two sessions were conducted for each participant: a familiarisation session and a testing session. CMJ familiarisation ensured that each participant could reproducibly perform a maximum effort jump consisting of one continuous movement with no pause at maximum knee flexion. No horizontal displacement between take-off and landing was permitted. Squat familiarisation required that each participant could squat to the prescribed depths with consistently good form, independent of load and tempo. Form was judged by an advanced

BODYPUMP^{TM} instructor, who conducted all sessions. Reps, sets and recovery were adjusted as required. The second session took place between 1 and 10 days after the familiarisation session (to accommodate participant availability). During the testing session, motion capture and EMG data were collected for CMJ and squat as described below.

CMJ and squats

Participants performed 5 x maximum effort CMJs with 1 minute rest between repetitions. Use of arms was permitted. Strong verbal motivation was employed. For squat analysis, four conditions were defined as follows: 90° knee angle depth + 23% bodyweight load (90D 23L); 90° knee angle depth + 38% bodyweight load (90D 38L); 125° knee angle depth + 23% bodyweight load (125D 23L); 125° knee angle depth + 38% bodyweight load (125D 38L). Knee angle was defined as the non-reflex angle between femur and tibia. A 90° knee angle squat was therefore deeper than a 125° knee angle squat. Participants performed 1 set of 7 repetitions for each of the four squat conditions with 3 minutes rest between trials.

90D is defined by Les Mills as a full depth squat, and is maximum squat depth during a BODYPUMP^{TM} class. 23L and 38L represent the 25th and 75th percentiles of the BODYPUMP^{TM} squat loads self-reported by participants prior to the study. Squat load was determined relative to bodyweight rather than by RM testing because BODYPUMP^{TM} participants are not familiar with testing to failure at any repetition range. Defining load as a percentage of bodyweight is therefore more valid and practically applicable.

Squat depth was controlled by requiring participants to contact a metal rod at the end of the descending phase. The height of the rod was determined by using motion capture data to calculate knee angle (see below). A ±5% error in knee angle was accepted. Participants were instructed to ‘tap the rod lightly’, and the rod structure was not sufficiently robust to allow muscle unloading. As muscle activity is dependent on movement speed (van den Tillaar et al., 2019), tempo was controlled by instructing participants to squat to a 65 beats per minute (bpm) metronome tone. 65 bpm is the mean tempo of 4 BODYPUMP^{TM} squat tracks released in 2018-2019. For 90D squats, the tempo was: 1.8 seconds descending phase, 1.8 seconds ascending phase. For 125D squats, the tempo was: 0.9 seconds descending phase, 0.9 seconds ascending phase. This resulted in equal movement speed as the mean knee angle between squat repetitions was 163.9 ± 3.5° (the loaded bar caused participants to maintain some knee flexion at the end of the ascending phase). The stance width adopted was BODYPUMP^{TM} mid-stance, which is defined as 'feet slightly wider than hips'. In response to this cue, participants self-selected a stance width of 1.5 ± 0.2 x inter-ASIS distance. As stance width can influence muscle activity (Paoli et al., 2009), participants were required to use an identical stance width for each of the four squat conditions.

Motion capture

Motion capture data were obtained using the Qualisys Motion Capture System (Qualisys, Gothenburg, Sweden) and Qualisys Track Manager software (Qualisys, Gothenburg, Sweden). Ten cameras were used to track retroreflective markers placed on the greater trochanter, lateral knee joint and lateral malleolus of the dominant leg. The capture rate was 250Hz. Motion capture data were synchronised with EMG data acquisition.

EMG

EMG data were acquired using the Bagnoli^{TM} EMG System (Delsys, Massachusetts, USA) and filtered to a bandwidth between 20Hz and 450Hz. DE-2.1 single differential surface EMG sensors were placed over vastus lateralis, gluteus maximus, biceps femoris and lateral gastrocnemius on the dominant leg. A reference electrode was placed on the medial malleolus. Both sensor and skin were cleaned with isopropanol wipes before sensor application. Sensors were positioned according to SENIAM guidelines (www.seniam.org; accessed 25/09/19). The sample rate was 1250Hz.

Data Analysis

Knee angle was calculated for CMJ and squat trials using Qualisys Track Manager software. For CMJ, the data were manually screened to locate the minimum knee angle prior to take-off. Trials where participants bent their knees in flight were excluded. Knee angle was also used to identify the descending and ascending phase of the middle 5 repetitions of every 7 repetition squat test.

EMG data analysis was performed using Spike 2 software (Cambridge Electronic Design Ltd, Cambridge, England). An RMS algorithm with a 100ms moving window was applied to each channel. Peak EMG values were determined for every CMJ repetition. Analysis was restricted to the take-off phase. The mean of the peak values was calculated for each muscle and used for data normalisation. For squat EMG analysis, mean and peak activity were calculated for the descending and ascending phase of the middle 5 squat repetitions of each trial. The mean of these values was calculated for each muscle and normalised against the CMJ data.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics software, version 24 (IBM, NY, USA). For ICC values, a two-way mixed model was used with absolute agreement. A threshold of 0.75 defined reliability (Suydam et al., 2017). Normalised EMG data were analysed using a three-way ANOVA with repeated measures (DEPTH x LOAD x PHASE; 2 x 2 x 2). A Shapiro-Wilk test confirmed that the data were normally distributed ($p > 0.05$). Statistical significance was defined as $p \leq 0.050$. Effect sizes (r) were also calculated. Effect sizes of 0.1, 0.3 and 0.5 were interpreted as small, medium and large respectively (Field, 2018). Standard deviations around the mean are reported.

Results

CMJ provides reliable EMG data as a result of repeatable knee joint kinematics. The mean minimum knee angle prior to take-off in the CMJ was 89.0 ± 10.6°. The associated intra-participant coefficient of variation (CV) fell in the range 1.3-7.3% (mean 3.8%). The inter-participant CV was 12.0%. Intra-class correlation coefficients for peak EMG activity in the CMJ are shown in *Table 2.*

Squat depth and load both influence lower body muscle activity. Normalised EMG data for vastus lateralis, biceps femoris, gluteus maximus and lateral gastrocnemius are shown in *Table* 3. *F*, *p* and *r* values for ANOVA output are shown in *Supplementary Data*.

The main effect of DEPTH was statistically significant for mean and peak activity of vastus lateralis and gluteus maximus, and for peak activity of biceps femoris and lateral gastrocnemius ($5.513 \leq F_{1,\,9} \leq 46.992$; $p \leq 0.043$; $0.38 \leq r \leq 0.84$). Mean activity of vastus lateralis was 1.3-1.4 fold greater at 90D than at 125D for 23L and 38L. Peak activity was 1.8-1.9 fold greater at 90D. However, for gluteus maximus, mean activity at 90D was not more than 1.1 fold greater than at 125D for 23L or 38L. Peak activity was 1.1-1.3 fold greater at 90D. Peak activity of biceps femoris and lateral gastrocnemius at 90D was respectively 1.2-1.3 fold and 1.2 fold greater than at 125D for 23L and 38L. The main effect of DEPTH was non-significant for mean activity of biceps femoris and lateral gastrocnemius ($1.115 \leq F_{1,\,9} \leq 3.630$; $p \geq 0.089$; $0.12 \leq r \leq 0.29$).

The main effect of LOAD was statistically significant for mean and peak activity of gluteus maximus and lateral gastrocnemius ($5.113 \leq F_{1,\,9} \leq 8.592$; $p \leq 0.050$; $0.36 \leq r \leq 0.52$). However, mean and peak activity of gluteus maximus and mean activity of lateral gastrocnemius were not more than 1.1 fold greater at 38L than at 23L for 90D or 125D. Peak lateral gastrocnemius activity was 1.1-1.2 fold greater at 38L. The main effect of LOAD was non-significant for mean and peak activity of vastus lateralis and biceps femoris ($0.009 \leq F_{1,\,9} \leq 4.928$; $p \geq 0.054$; $0.00 \leq r \leq 0.35$).

The main effect of PHASE was statistically significant for mean and peak activity of gluteus maximus and for mean activity of biceps femoris ($5.118 \leq F_{1,9} \leq 15.610$; $p \leq 0.050$; $0.36 \leq r \leq 0.63$). Mean and peak activity of gluteus maximus in the ascending phase was 1.1-1.2 fold greater than in the descending phase. However mean biceps femoris activity in the ascending phase was not more than 1.1 fold greater than in the descending phase. The main effect of PHASE was non-significant for mean and peak activity of vastus lateralis and lateral gastrocnemius, and for peak activity of biceps femoris ($0.103 \leq F_{1,9} \leq 5.118$; $p \geq 0.054$; $0.01 \leq r \leq 0.39$).

The LOAD*PHASE interaction was statistically significant for mean activity of gluteus maximus ($F_{1,9} = 7.483$, $p = 0.023$, $r = 0.45$). The effect of LOAD was greater in the ascending phase than in the descending phase. All other interactions were non-significant for mean and peak activity of all muscles.

Discussion and Implications

This is the first study to examine the effect of squat depth and load on muscle activity in BODYPUMP^{TM} participants. The mean and peak activity of vastus lateralis and gluteus maximus, and the peak activity of biceps femoris and lateral gastrocnemius, were significantly greater in a 90D squat than in a 125D squat. Peak activity of vastus lateralis in a 90D squat approached double that in a 125D squat. The mean and peak activity of gluteus maximus and lateral gastrocnemius were significantly greater in a 38L squat than in a 23L squat. These data can be used to inform BODYPUMP^{TM} coaching recommendations and maximise the effectiveness of participation in group exercise classes.

As a result of repeatable knee joint kinematics, CMJs generated reliable peak EMG data for normalisation of vastus lateralis, gluteus maximus and lateral gastrocnemius activity

(ICC 0.91, 0.76 and 0.92 respectively). Peak EMG data for biceps femoris approached the threshold for reliability (ICC 0.72, threshold 0.75). The reliability of vastus lateralis, gluteus maximus and lateral gastrocnemius EMG data may reflect the fact that the vasti, gluteus maximus and gastrocnemius are the primary muscles required at take-off (Nagano et al., 2017). Use of CMJ circumvents the controversy surrounding the optimal MVIC protocol for vastus lateralis and gluteus maximus, and generates peak EMG values that are greater than those obtained in a BODYPUMP^{TM} squat.

Even within the constraints of BODYPUMP^{TM} technique, squat depth has an important effect on muscle activity. Mean and peak activity of vastus lateralis and gluteus maximus, and peak activity of biceps femoris and lateral gastrocnemius, were significantly greater in a 90D squat than a 125D squat. The effect of squat depth on vastus lateralis activity was especially marked; mean and peak activity at 90D was up to 1.41-fold, and up to 1.87-fold greater than at 125D respectively. Vastus lateralis activity may be particularly dependent on squat depth as maximum vastus lateralis activity has been reported to occur around the point of maximum knee flexion in both a parallel (posterior surface of the thigh parallel to the floor) and 90D squat (McCaw & Melrose, 1999; Yavuz & Erdag, 2017). Activity of gluteus maximus and biceps femoris, in contrast, is greatest in the ascending phase (Yavuz & Erdag, 2017).

In contrast to the analysis reported here, previous studies have not found an effect of squat depth on the activity of vastus lateralis, gluteus maximus, biceps femoris or lateral gastrocnemius (Contreras et al., 2016; Gorsuch et al., 2013). It is likely that this effect was masked by the use of depth-specific 10RM to determine load. Reduced load in the deeper squat would have limited the requirement for muscle activity that would otherwise have resulted from greater depth. The ability to detect an effect of depth on muscle activity is also enhanced by the introduction of CMJ as a reliable reference for normalising squat EMG data. Adopting a single dynamic reference is likely to reduce the variance of the dataset and therefore increase statistical power compared to the inconsistent use of different MVIC protocols reported previously (Contreras et al., 2016).

This is the first study to report the effect of squat load on lateral gastrocnemius activity. It is also the first time that the effect of load on gluteus maximus, vastus lateralis and biceps femoris activity has been investigated in non-strength trained participants. Previous analyses of gluteus maximus, vastus lateralis and biceps femoris activity in strength-trained participants are conflicting; both a significant effect and no effect of load have been reported (McCaw & Melrose, 1999; Paoli et al., 2009; van den Tillaar et al., 2019; Yavuz & Erdag, 2017). This inconsistency may be explained by the non-linear relationship between load and muscle activity reported by van den Tillaar et al. (2019). A non-linear relationship suggests that the exact loads investigated, and the magnitude of the difference between them will determine whether a significant effect of load on muscle activity is found. However, when no significant load effect is identified, a non-significant increase in muscle activity with increasing load is consistently reported (McCaw & Melrose, 1999; Paoli et al., 2009; Yavuz & Erdag, 2017). The extra force needed to lift a greater load may therefore be generated by several hip, knee and ankle extensors, but with each muscle making only a small additional contribution. In this case, the identification of a significant load effect may be particularly dependent on statistical power, leading to the observed inconsistency between analyses.

The low load, high repetition design of BODYPUMP^{TM} is characteristic of strength-endurance rather than maximal strength training. The highest normalised peak EMG values observed in any of the depth or load conditions studied were: vastus lateralis, 58%; gluteus maximus, 37%; biceps femoris, 31% and lateral gastrocnemius, 13%. As training for maximal strength involves loads of at least 80% 1RM (Kraemer et al., 2002), and the limiting joint in a failed squat is the hip or knee (Flanagan et al., 2015), an 80% 1RM load would be expected to elicit peak EMG values of approximately 80% in one or more hip or knee muscles. Despite the relatively low peak EMG values observed in BODYPUMP^{TM}, participation has been shown to increase predicted squat 1RM (Greco et al., 2011) and leg press 1RM (Nicholson et al., 2015). However, these studies were conducted in untrained individuals. For regular participants, factors other than peak EMG may drive muscular adaptation to BODYPUMP^{TM} training. In regular BODYPUMP^{TM} participants, blood lactate post-class is significantly higher than pre-class (5.8 ± 3.0 mmol/L, 2.2 ± 0.9 mmol/L respectively), and the degree of elevation is significantly greater than that observed after iso-caloric, iso-time steady state cycling (Harris et al., 2018). Metabolic demand, resulting from the very high repetition nature of BODYPUMP^{TM}, may therefore provide an important stimulus for development of local muscle endurance. Consistent with this hypothesis, Gorostiaga et al. (2012) showed that compared to 10 sets of 5 leg press, 5 sets of 10 repetitions caused a greater depletion of energy stores, a higher level of muscle lactate and a greater decrease in power output. In combination with other central and peripheral mechanisms, the metabolic demand of high repetition training in BODYPUMP^{TM} may cause fatigue of type I muscle fibres, necessitating recruitment of high threshold type II motor units to maintain force production. Thus fatigue may also be an important component of the BODYPUMP^{TM} training stimulus.

Increased load caused a significant increase in the mean and peak activity of gluteus maximus and lateral gastrocnemius. However, the fold changes in muscle activity were ≤1.17. These relatively small increases in muscle activity may not be sufficient to generate a practically meaningful change in maximal strength. In combination with very high repetition training, however, a small increase in muscle activity may be sufficient to substantially increase metabolic demand, and therefore fatigue. The additive effect of a small increase in the activity of gluteus maximus, lateral gastrocnemius, and possibly other untested muscles, may therefore lead to a practically relevant improvement in the strength-endurance of the lower body.

EMG-based estimation of muscle force during dynamic contractions is complicated by the effect of muscle length and contraction velocity on force-producing capacity (Staudenmann et al., 2010). Bryanton et al. (2012) used an inverse dynamics approach to calculate the effect of squat depth (119°-30° knee flexion) and load (50-90% 1RM) on relative muscular effort (RME) of the hip extensors, knee extensors and ankle plantarflexors. RME is the ratio of net joint moment to maximum voluntary torque, matched for joint angle. Consistent with the EMG data presented here, greater squat depth increased the RME of the hip extensors and knee extensors. Greater load increased the RME of the hip extensors and ankle plantarflexors (Bryanton et al., 2012). In addition to these common findings, the EMG data reported above show an effect of depth on the peak activity, but not mean activity, of lateral gastrocnemius. This difference is likely to reflect the increased inter- and intra-participant variability of ankle net joint moments compared to those of the hip and knee (Flanagan & Salem, 2008). Lorenzetti et al. (2012) also used inverse dynamics to calculate the effect of 0%, 25% and 50% bodyweight load on maximum knee and hip moments. Increasing load caused a significant increase in both hip and knee moment, but the fold change for the hip moment was greater than for the knee moment (Lorenzetti et al., 2012). This data is consistent with analysis of the effect of load on the relative contribution of the hip, knee and ankle. Flanagan and Salem (2008) investigated 25, 50, 75 and 100% 3RM, and showed that the contribution of the hip and ankle to the support moment (the sum of the average net joint moments for the hip, knee and ankle) significantly increased between load conditions, except between 75% and 100%. The contribution of the knee significantly decreased between all loading conditions (Flanagan & Salem, 2008). These results align with the data presented here, which show a significant effect of load on the mean and peak activity of gluteus maximus and lateral gastrocnemius, but not vastus lateralis. A further inverse dynamics-based analysis reported the effect of squat depth on peak knee extensor moment. Flores et al. (2020) found that at 50% and 85% of depth-specific 1RM, peak knee extensor moment was greater in a full depth (135° knee flexion) squat than in a parallel (110° knee flexion) squat, but there was no significant difference between a parallel and above parallel (90° knee flexion) squat. However, as a different absolute load was used at each squat depth, the effect of depth cannot be separated from the effect of load. Inverse dynamics data are therefore in good agreement with this EMG-based analysis of squat biomechanics. An important limitation of inverse dynamics is that the net joint moment is the sum of all agonist and antagonist moments acting at a joint. The knee extensor net joint moment therefore underestimates the torque generated by the quadriceps due to co-contraction of the hamstrings (Bryanton et al., 2012). The magnitude of the error depends on the hip extensor strategy used during the squat i.e. the relative contribution of gluteus maximus and hamstrings (Bryanton et al., 2015). EMG data are therefore required to establish the effect of squat depth and load on muscle activity.

In the absence of longitudinal data, it remains unknown whether the increased muscle activation observed in the 90D and 38L conditions is sufficient to result in enhanced maximal strength or strength endurance-related adaptation over time. However, the data shown suggest that in order to facilitate acquisition of lower body strength-endurance, BODYPUMP^{TM} participants should squat to a full 90D to promote activation of vastus lateralis, gluteus maximus, biceps femoris and lateral gastrocnemius. Coaches should also encourage incremental increases in load to provoke greater gluteus maximus and lateral gastrocnemius activity. Several parameters that influence muscle activity in BODYPUMP^{TM} are shared with other group exercise classes. For example, range of motion is modified to accommodate the recreational population, light weights are used in combination with a high number of repetitions, and the speed of movement is determined by the tempo of music. In addition, BODYPUMP^{TM} participants are likely to be representative of healthy adults participating regularly in conditioning-based activities. The above findings may therefore be broadly relevant in a group exercise setting.

Conclusion

Group exercise classes are rapidly growing in popularity and make an important contribution to public health. This study showed, using a practically relevant experimental design, that both squat depth and load affect muscle activation in BODYPUMP™ participants. Increased depth significantly increased the mean and peak activity of vastus lateralis and gluteus maximus, and the peak activity of biceps femoris and lateral gastrocnemius. Greater load increased the mean and peak activity of gluteus maximus and lateral gastrocnemius. These data can be used to inform BODYPUMP™ programme design and enhance the training effect of participation in group exercise classes.

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Declaration of Interest

No financial or other benefit has arisen from this research

Data Availability Statement

Data can be found at DOI: 10.17632/48hx5885ry.1

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Table 1: Descriptive data for study participants.

Age (years)	41 ± 9
Height (cm)	161.9 ± 3.8
Body mass (kg)	67.7 ± 7.0
BODYPUMP^{TM} classes per week	2 ± 1
Inter-ASIS distance (cm)	25.7 ± 1.9
Stance width (cm)	37.6 ± 3.8

ASIS: Anterior Superior Iliac Spine

Table 2: Intra-class correlation coefficients (ICCs) for CMJ EMG data.

MUSCLE	**ICC**	**95% Confidence Interval**
Lateral gastrocnemius	0.917	(0.794-0.978)
Gluteus maximus	0.764	(0.505-0.931)
Biceps femoris	0.724	(0.445-0.917)
Vastus lateralis	0.912	(0.784-0.976)

Table 3: Normalised mean and peak EMG values for all muscles tested in the four squat conditions under study.

			Normalised Muscle Activity (%)			
			Depth: 90° Load: 23%	Depth: 90° Load: 38%	Depth: 125° Load: 23%	Depth: 125° Load: 38%
LG	Mean #	D	7.1 ± 2.2	7.2 ± 2.2	6.9 ± 2.2	7.4 ± 2.4
		A	7.5 ± 2.4	8.0 ± 2.6	7.4 ± 2.4	7.6 ± 2.6
	Peak *#	D	10.5 ± 3.6	12.2 ± 4.0	9.1 ± 2.9	10.6 ± 4.1
		A	11.0 ± 3.9	12.7 ± 4.4	9.2 ± 3.5	10.2 ± 3.7
GM	Mean *#	D	23.1 ± 13.0	23.2 ± 13.0	22.4 ± 12.8	22.7 ± 12.9
		A	24.7 ± 12.4	25.9 ± 12.8	23.6 ± 12.2	23.8 ± 12.7
	Peak *#	D	29.4 ± 12.9	31.4 ± 12.4	26.3 ± 12.7	26.0 ± 13.4
		A	33.6 ± 12.1	37.3 ± 13.6	28.5 ± 12.4	29.0 ± 13.7
BF	Mean	D	17.8 ± 7.0	18.2 ± 7.4	16.6 ± 5.8	17.2 ± 6.5
		A	19.0 ± 8.0	20.0 ± 8.9	17.4 ± 5.6	18.0 ± 6.0
	Peak *	D	26.9 ± 8.0	26.9 ± 9.3	23.0 ± 7.0	22.4 ± 6.2
		A	30.2 ± 11.6	30.8 ± 12.5	23.6 ± 8.7	24.2 ± 8.6
VL	Mean *	D	22.5 ± 3.9	23.8 ± 4.6	15.9 ± 4.8	17.1 ± 5.1
		A	23.7 ± 5.1	25.2 ± 5.1	18.2 ± 6.6	19.2 ± 6.3
	Peak *	D	51.5 ± 10.7	56.4 ± 12.4	29.1 ± 8.8	30.7 ± 8.5
		A	53.4 ± 10.4	58.1 ± 13.3	28.6 ± 8.5	31.3 ± 9.0

LG = lateral gastrocnemius, GM = gluteus maximus, BF = biceps femoris, VL = vastus lateralis, D = descending phase, A = ascending phase, 90° = 90° knee angle, 125° = 125° knee angle, 23% = 23% bodyweight, 38% = 38% bodyweight.

* = significant main effect of depth, # = significant main effect of load.