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Effect of increasing the mass of the ball on power output during the overarm throw in professional male handball players

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Abstract

This study aimed to determine the effect of increasing the mass of the official handball ball on horizontal force, velocity, and power outputs. Twelve male handball players from the Spanish Asobal Handball League performed overarm throws with four balls: official (0.460 kg), Δ15% (0.529 kg), Δ45% (0.667 kg), and Δ75% (0.805 kg). The throws were filmed with two cameras temporally synchronized at 250 Hz and digitized at 125 Hz, making possible to obtain the spatial coordinates of a model composed by six body markers plus the geometric center of the ball. Incrementing the mass of the ball produced a progressive reduction in velocity and increase in force ($p < 0.001$). The power tended to increase with the increment of the mass, but significant differences were only reached for the heaviest condition (Δ75%) and it was linked to changes in the application of force with respect to time. The maximum values of force, velocity and power with respect to the release of the ball, were delayed with the increment of the mass ($p < 0.001$). These results evidence that the power applied to the ball can only be increased when heavy balls, which modify the structure of the throw, are used.

Keywords

Biomechanics, force, handball, temporal analysis, throwing, velocity, video analysis

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Introduction

Throwing balls heavier than the official handball ball has been present in the training routines of team handball players for decades.[1] This proposal is justified by the possibility of training with force overloads while performing movements similar to those performed in competition (specificity principle). It has been well known – since Hill promulgated in 1938 the inverse force-velocity relationship, that the force a muscle can produce increases with the decrease of its shortening velocity.[2] Because the velocity that can be reached in different exercises decreases with the increment of resistance,[3,4] it would not be surprising that handball players can develop higher force values when throwing balls heavier than the official handball ball. However, it is important to note that the overarm throw involves a proximal-distal sequence of ballistic muscle contractions in which eccentric and concentric muscle actions follow one another.[5–7] This sequence of muscle participation is far from the conditions in which Hill described the force-velocity curve. In this regard, it is also important to note that the potential benefits of overloaded specific training are not conclusive.[8–10]

Numerous studies have explored the effect of increasing the mass of the ball on throwing kinematics, concluding that the maximum velocity reached by the ball decreases as its mass increases.[7,11–14] These studies

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revealed that, while the coordinative structure of movement was not altered, the decrease in the velocity of the ball at the moment of release was linked to changes in the maximum angular velocity of internal rotation of the shoulder, the range of angular displacement of the elbow, and the maximum velocity of rotation of the trunk. For example, van den Tillaar and Ettema[15] found a reduction of 4.3% in the maximum throwing velocity when the mass of the ball was increased by a 20%, and this reduction was attributed to a lower angular velocity of both the internal rotation of the shoulder and the extension of the elbow.

The kinematic data presented above confirms the theory about the force-velocity curve proposed by Hill,[2] although for this it would be necessary to establish the relationship between the applied muscle force and the mass of the balls. However, the rate at which muscle force increases relative to the increment of the mass of the ball remains unknown. The truth is that assessing muscle strength during handball throws executed at maximum intended velocity constitutes a scientific challenge. In addition to the mass of the ball, it is necessary to consider that overarm throws are complex accelerated movements that involve the sequential transfer of partial muscular impulses that mobilize their respective segments, which do not always act in the same direction as the throw. This is important because force components acting perpendicular to the direction of the throw do not contribute to the final velocity of the ball at the release.

To our knowledge, no study has directly examined the muscular force exerted during handball throws, while the studies that have examined the force exerted on the ball are still scarce. Van den Tillaar and Ettema, using the inverse dynamic approach through video analysis, revealed a negative linear relationship between the maximal values of velocity and force applied to the ball.[14] Cross[16] also suggested that there is a constant positive linear relationship between the mass of the ball and the applied force. These two contributions are oriented toward an inertial conception of the mass, from which it is possible to verify that more force is applied when lifting a mass of 30 kg compared to a mass of 1 kg. During throws performed at maximal intended velocity, it has been verified that at reduced velocities ($\leqslant 6$ m/s) the applied force increases proportionally to the mass of the ball.[16] On the other hand, when it comes to achieving maximum velocity at the end of a given acceleration distance, the increase in the mass of the ball decreases its velocity at the release. These facts allow us to verify that the applied force increases at a slower rate than the mass of the ball, and this is accentuated when mobilizing very heavy loads for which the applied force remains almost identical despite the change of the load. In this sense, it should be considered that, if the increase in force was proportional to the increase in mass, the final velocity would be the same regardless of the mass of the ball.

In response to limited research regarding the force applied during the overarm throw and following the inertial conception, this study aimed to determine the effect of three increases in the mass of the official handball ball (Δ15%, Δ45%, and Δ75%) on the horizontal force, velocity, and power applied to the ball during an overarm throw performed by expert team handball players through video analysis. These loads were selected because our previous research has shown that (i) an increment of 15% does not affect the throwing kinematics, (ii) increments of 30%, 45%, and 75% progressively reduce the throwing velocity but the temporal and spatial structure of the movement remains unchanged, and (iii) an increment of 75% modifies both throwing velocity and the structure of the movement.[7] Therefore, we selected three loads that could differentially affect throwing kinematics. We hypothesized that the increment in the mass of the ball would reduce the maximal horizontal velocity ($\boldsymbol{v}_X$) and increment the maximal horizontal force ($\boldsymbol{F}$x) applied to the ball, while the maximal power ($\boldsymbol{P}$) would increase because the increment of the mass of the ball was expected to have a greater influence on strength gains than on velocity losses.

Methods

Experimental approach to the problem

After performing their regular 15 min handball-specific warm-up, participants stood 13 m in front of the goal, ready to receive a pass from their non-dominant side. After the reception of the ball, participants were instructed to perform the overarm throw in support, at maximal velocity, in the shortest possible time, and in the direction of the upper middle zone of the goal. Participants were allowed to make their routine movements prior to performing the throws. They were allowed to use resin (to aid grip) and perform practice trials with the different ball conditions before starting their respective data collection.

Participants randomly performed four blocks of three throws. The only difference between the blocks was the mass of the ball: official (0.460 kg), Δ15% (0.529 kg), Δ45% (0.667 kg), and Δ75% (0.805 kg). A rest between throws of the same and different blocks was set at 2 and 10 min, respectively. The increase in the mass was done by unstitching the ball and adding mass around the internal surface with the aim of not altering the dimensions of the ball and texture due to the use of resin.

Subjects

Twelve males specializing in first-line throwing and belonging to teams from the Spanish Asobal Handball League (age: 26.2 ± 2.6 years; body mass: 92.8 ± 13.7 kg; stature: 1.89 ± 0.07 m) volunteered to participate in this study. All participants were informed

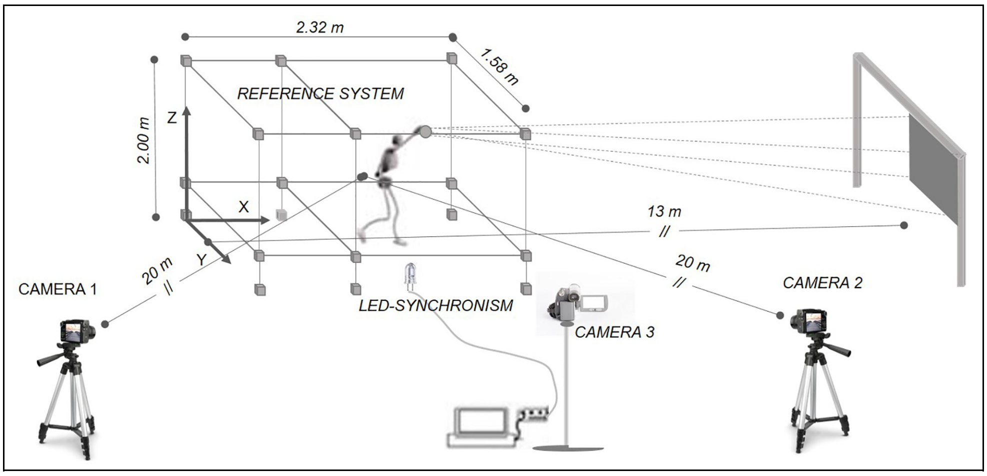

Figure 1. Schematic representation of the experimental setup and recording systems.

about the study details and signed an informed written consent form before the study onset. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

Procedures

In order not to interfere with movement, all trials were recorded with two video cameras at 250 Hz (JVC GC-PX100BE, JVC-Kenwood Corporation, Yokohama, Japan). The two cameras were located on the dominant side of the participant, 20 m away from the geometric center of the throwing zone, and they were separated from one another by 30 m (Figure 1). The two cameras were temporarily synchronized by turning on a LED in the common field of view. A third video camera (CASIO EX-FH20, Casio Computer Co., Tokyo, Japan) was positioned perpendicular to the throwing direction and sampled the video at 420 Hz. Before the recording of any trial, a reference framework ($2.32 \times 1.58 \times 2.00$ m) was located in the throwing area. The framework was filmed for the purpose of performing the kinematic analysis and later it was removed from the throwing area before the throws were performed. The framework's horizontal axis (X) was associated with the ground and was perpendicular to the plane of the goal (throwing direction); the transverse axis (Y) was associated with the ground and was perpendicular to the previous one; the vertical axis (Z) was perpendicular to the other two.

From the three trials performed in each block, only the one that showed the median velocity value at the release was considered for further analyses. The horizontal velocity at the release was obtained using a 2D analysis from the images recorded with the camera located perpendicular to the direction of the throw (third camera). The dimensions of the ball were considered as a reference system to scale the displacements of the geometric center of the ball. For the selected throws, we determined the three-dimensional coordinates of six body points (center of the hip joint on the dominant side, both shoulders, elbow, wrist, and end of the third finger on the dominant side) plus the point corresponding to the geometric center of the ball. After the temporal synchronization of the images obtained by the two cameras, the process of obtaining the spatial coordinates was carried out in three steps: (i) the positions of the seven markers were digitized at 125 Hz from the images recorded by of the two video cameras, (ii) the direct linear transformation method was used to obtain the spatial coordinates,[17] and (iii) spline functions raised to the fifth power were applied to interpolate said coordinates at a frequency of 250 Hz.[18]

Data analysis

For each consecutive time interval ($\Delta t = 0.004$ s), the mean horizontal velocity of the geometric center of the ball ($\boldsymbol{v}_X$) was determined. The average power applied to the ball was then calculated from the change in kinetic energy for each time interval, according to the following expression:

$$P = \frac{m(v_{X(f)}^2 - v_{X(i)}^2)}{2 \cdot \Delta t}$$

where P is the mean power of each time interval; m represents the mass of the ball; $\mathbf{v}_{X(f)}$ and $\mathbf{v}_{X(i)}$ correspond to the horizontal velocity of the geometric center of the ball at the end and start of each time interval, respectively; and Δt is the duration of each time interval (0.004 s).

The mean horizontal force of each time interval was calculated as the mean power divided by the mean horizontal velocity. The angular displacement of the shoulders and the consecutive angular positions of internal/external rotation of the shoulder were determined following the methodology proposed by Gutiérrez-Dávila et al.[7]

Table 1. Comparison between the four throwing conditions of the maximal horizontal velocity (maximal $\mathbf{v}_X$), maximal horizontal force (maximal $\mathbf{F}_X$), maximal power (maximal **P**), and the temporal variables.

	Official (0.460 kg)	Δ15% (0.529 kg)	Δ45% (0.667 kg)	Δ75% (0.805 kg)	F
Maximal v_X (m/s)	25.07 ± 1.62	24.10.1 ± 1.46[1]	22.47 ± 1.65[1,2]	20.73 ± 1.82[1,2,3]	16.1***
Maximal F_x (N)	159.5 ± 31.5	178.5 ± 30.7[1]	194.8 ± 26.2[1]	221.0 ± 29.5[1,2,3]	7.3**
Maximal P (W)	3233.6 ± 671.5	3368.9 ± 686.9	3540.4 ± 578.0	3895.8 ± 654.9[1,2,3]	3.7
Temporal variables					
Recoil phase duration (s)	0.076 ± 0.014	0.078 ± 0.013	0.085 ± 0.012[1,2]	0.090 ± 0.016[1,2]	8.5**
Acceleration phase duration (s)	0.082 ± 0.015	0.083 ± 0.010	0.086 ± 0.013	0.093 ± 0.015[1,2]	4.5*
Time to maximal v_X (s)	−0.001 ± 0.001	−0.001 ± 0.001	−0.001 ± 0.002	−0.003 ± 0.002[1,2,3]	4.0*
Time to maximal F_X (s)	−0.022 ± 0.006	−0.024 ± 0.006	−0.026 ± 0.006	−0.032 ± 0.006[1,2,3]	5.1*
Time to maximal P (s)	−0.017 ± 0.005	−0.019 ± 0.006	−0.023 ± 0.003[1,2]	−0.028 ± 0.003[1,2,3]	16.5***

The time to the maximum values are negative because they are expressed with respect to the point of take-off of the ball.
[1,2,3]Represent significant differences with respect to the official ball, Δ15%, and Δ45%, respectively ($p < 0.05$).
***$p < 0.001$. **$p < 0.01$. *$p < 0.05$.

The temporal analysis considered three events: (t1) beginning of the rotation of the shoulders toward the throwing direction, considered as the middle of the interval where the angular displacement of the line joining the two shoulders becomes positive and maintains this tendency; (t2) maximal external rotation of the shoulder; and (t3) release of the ball from the hand, considered as the instant in which the distance between the point that defines the end of the third finger and the geometric center of the ball became greater than the radius of the ball (0.09 m). The throwing duration has been defined as the time elapsed between t1 and t3. To deepen in the temporal analysis, two phases have been distinguished: recoil phase (between t1 and t2) and acceleration phase (between t2 and t3). To illustrate the force-, velocity-, and power-time curves, the data was resampled using interpolation with splines raised to the fifth power to express values in percentages of the total throwing time (100% corresponded to the total throwing duration).

Statistical analyses

Descriptive data are presented as means ± standard deviations. The normality of the variables was confirmed by the Shapiro-Wilk test (p ranged from 0.122 to 0.942). A repeated measures analysis of variance (ANOVA) with Fisher's least significant differences post hoc corrections, was applied to each dependent variable to compare the different throwing conditions (official mass [0.460 kg], Δ15% [0.529 kg], Δ45% [0.667 kg], and Δ75% [0.805 kg]). Statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

Results

Descriptive values of the dependent variables (maximal v_X, maximal F_X, maximal P, and temporal variables) and their comparisons between the throwing conditions (ball mass of 0.460, 0.529, 0.667, and 0.805 kg) are presented in Table 1. The maximal v_X was progressively reduced with the increment of the mass of the ball ($F = 16.1$; $p < 0.001$). The maximal F_X was progressively increased with the increment of the mass of the ball ($F = 7.3$; $p < 0.01$), but no significant differences were reached between the two intermediate ball masses (0.529 kg vs 0.667 kg; $p = 0.064$). The ANOVA applied to maximal P did not detect significant differences between the throwing conditions ($F = 3.7$; $p = 0.055$), but the pairwise comparisons only revealed a greater maximal P for the heaviest mass (0.805 kg) compared to the remaining throwing conditions.

Regarding the temporal variables, the duration of the recoil and acceleration phases tended to increase with the increment in the mass of the ball ($F = 8.5$, $p < 0.01$; $F = 4.53$, $p < 0.05$, respectively). The throwing conditions also differed for the time elapsed between the release of the ball and the point when the maximum values of v_X ($F = 4.0$, $p < 0.05$), F_X ($F = 5.1$, $p < 0.05$), and P ($F = 16.5$; $p < 0.001$) were reached. In general, the time elapsed between the release of the ball and the points where the maximum values were reached, increased with the increment in the mass of the ball. However, pairwise comparisons only revealed significant differences for the heaviest mass (0.805 kg) compared to the remaining throwing conditions (0.460, 0.529, and 0.667 kg) for the three variables, and in the case of maximal P also between the second heavier ball (0.667 kg) and the two lightest balls (0.460 and 0.529 kg).

The visual inspection of the velocity-time curves indicates that during the recoil phase the horizontal velocity is similar for the four throwing conditions, obtaining its greatest increase in the second half of the acceleration phase while the maximum velocity is obtained very close to the end of the acceleration phase (Figure 2). The horizontal force applied to the ball is close to 50N during all throwing conditions, and only with the heaviest ball overcame the 50N at the end of the recoil phase. As expected, the horizontal force sharply increased at

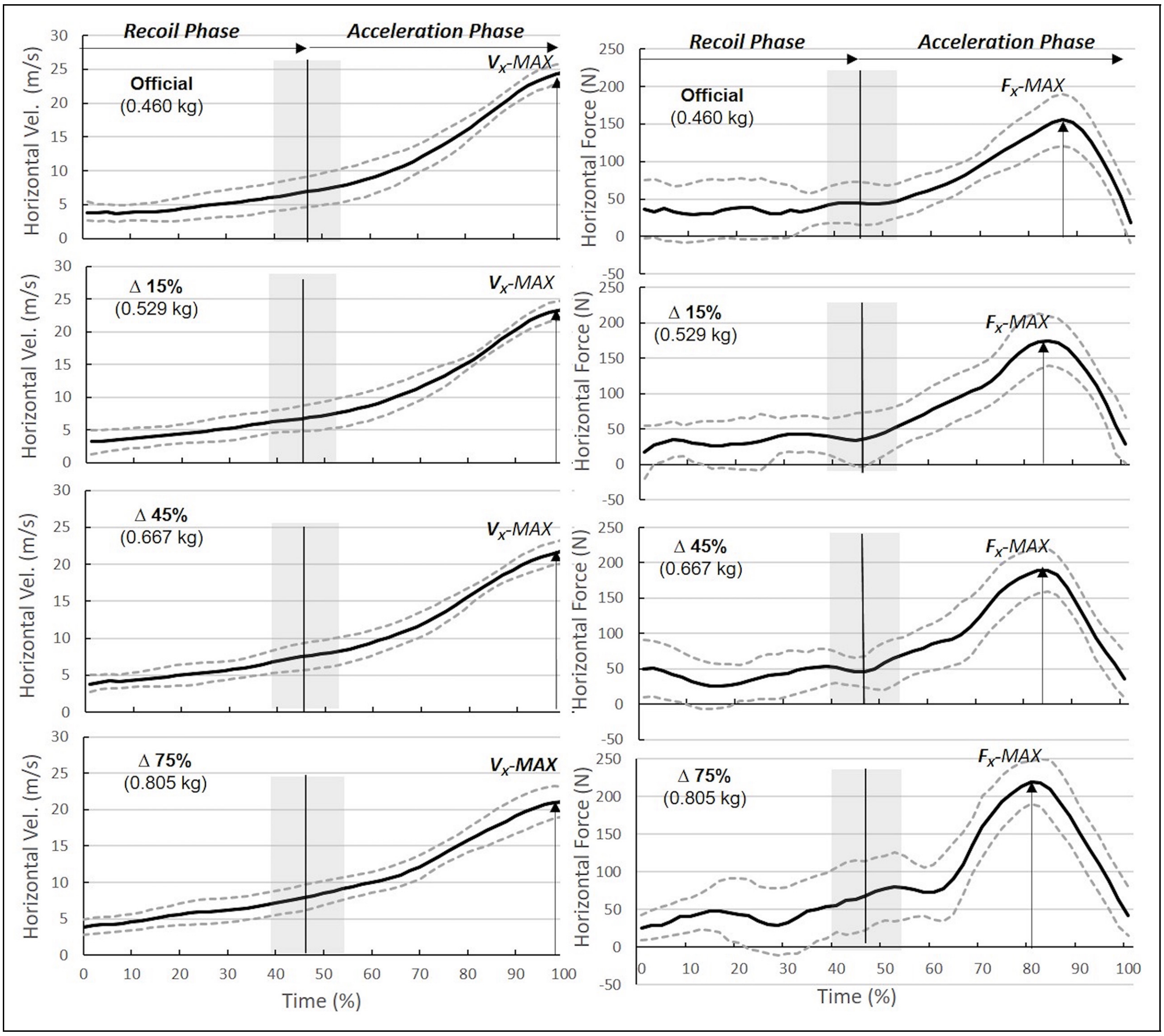

Figure 2. Horizontal velocity- and force-time curves obtained for the four throwing conditions. The straight black lines represent the data averaged across the subjects and the dashed gray lines their standard deviations. Vertical lines represent the average point when the acceleration phase was initiated and the shaded are the standard deviation. The arrows highlight the points when the maximal velocity (V_x-MAX) and maximal force (F_x-MAX) were reached.

the beginning of the acceleration phase (approximately at 46% of the total throwing duration), but the sharply increase in force was produced later for the heaviest ball (approximately at 60% of the total throwing duration). The maximum horizontal force applied to the ball was obtained approximately at 87% of the total throwing duration for the official ball, Δ15%, and Δ45% conditions, but for the Δ75% condition the point of maximal horizontal force was obtained before (approximately at 82% of the total throwing duration).

The power-time curves depicted in Figure 3 indicated that the sharp increase in power was obtained at the beginning of the acceleration phase, but this increase tended to be delayed with the increment in the mass of the ball. Confirming the results presented in Table 1, it was also observed how the increment in the mass of the ball promotes that the point when the maximum power is achieved is farther from the point of the release of the ball.

Discussion

The numerical data indicate that, when the mass of the ball increases, the maximum horizontal velocity is reduced and the maximum horizontal force applied to the ball is increased. These results are similar to those reported by van den Tillaar and Ettema[14] for expert team handball players using similar ranges of ball mass, while the differences between throwing conditions are slightly higher than those reported by Cross[16] for student non-experts in handball. The maximum power tends to increase with increasing ball mass, although the differences were only significant for the heaviest ball. The higher power outputs observed with

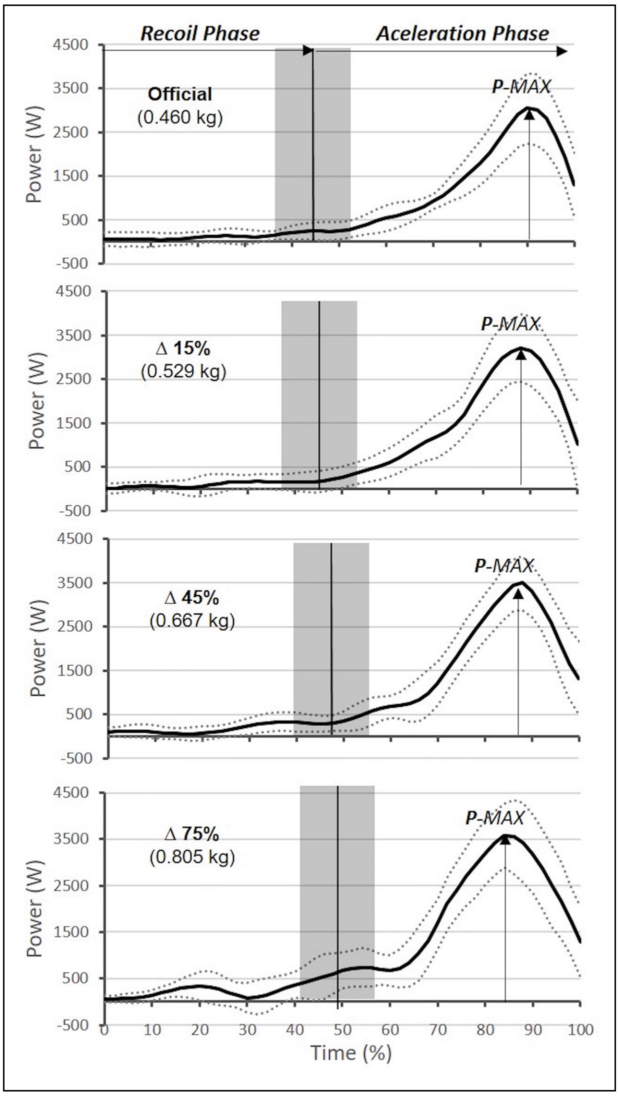

Figure 3. Power-time curves obtained for the four throwing conditions. The straight black lines represent the data averaged across the subjects and the dashed gray lines their standard deviations. Vertical lines represent the average point when the acceleration phase was initiated and the shaded are the standard deviation. The arrows highlight the point when the maximal power (P-Max) was reached.

increasing ball mass indicate that increasing the ball mass affects proportionally more force increase than velocity decrease. The increment of the mass of the ball by 75% could be related to changes in the structure of the movement, as it is suggested by the force- and power-time curves of the acceleration phase obtained in this study as well as by the data reported in our previous investigations.[7] The change in the structure of the movement differs from the results reported by Cross[16] and van den Tillaar and Ettema[14] likely due to the use of different procedures and samples with different levels of expertise.

The results of this study could be explained by the force-velocity curve proposed by Hill[2] for isolated muscles acting under purely concentric conditions. However, the different conditions in which the muscles are acting during maximal throws casts doubt on the force-velocity curve proposed by Hill as an explanatory theory. In this regard, it is important to note that the impulse applied to the ball during the acceleration phase is caused by a proximal-distal sequence of ballistic muscle contractions in which eccentric and concentric muscle actions follow one another.[7,19,20] Considering the type of contraction, it is more appropriate to use explanatory theories related to the stretch-shortening cycle[21,22] or neural activation.[23] The gains in throwing velocity obtained following plyometric training[24,25] or using a ball lighter than the official handball[8,26] could support these two alternative theories.

In the present study we observed a lower increase in the maximal $\boldsymbol{F}_x$ applied to the ball with respect to the increase of its weight (maximal $\boldsymbol{F}_x$ relative to the ball weight = 35.4 ± 6.9 for the official ball, 34.3 ± 5.9 for Δ15%, 29.8 ± 4.0 for Δ45%, and 28.0 ± 3.7 for Δ75%). These data confirm the findings by Cross,[16] suggesting that, for the range of masses used in this study, the reduction in velocity due to the effect of the increase in mass is caused because the maximum force applied to the ball increases at a lower rate than the weight of the ball. The explanation for this fact could be related to the time required by the muscles to produce force, which would be justified by the higher duration of the acceleration phase when throwing heavier balls (see Table 1). It is plausible that the force applied to the ball could remain constant at higher masses, as suggested by Cross[16] for ball masses that ranged from 2 to 3.5 kg. These results evidence that the rate of force development, which depends on both morphological factors and neural activation,[27] is a decisive factor to optimize overarm throwing performance.

The temporal analysis suggests a certain displacement of the time point in which the maximal $\boldsymbol{v}_x$ is reached with respect to the release of the ball. However, it is important to note that the differences between the means were always lower than the time interval used in this study (0.004 s), so it is plausible that the maximum velocity of the ball was in fact reached at its release for all throwing conditions. The maximal $\boldsymbol{F}_x$ was reached before (approximately at the 87% of the total duration), but in this case it is important to highlight that this point was displaced for the heaviest condition (Δ75%) in which the maximal $\boldsymbol{F}_x$ is obtained before (approximately at the 82% of the total duration). Similarly, the time in which the maximal $\boldsymbol{P}$ is reached is farther from the release as the mass of the ball increases. This tendency in the displacement of maximal force, velocity, and power values with respect to the release of the ball when the mass of the ball is increased, is in line with the muscular adaptations to the increase of the mass lifted as described in previous investigations.[28,29] Specifically, the longer duration of the throw with the heaviest condition (Δ75%) could accentuate fatigue and, consequently, prevent the maximum force (and power) values from being reached at the end of the movement.

The force- and power-time curves also showed a delay in their definitive increments with respect to the start of the acceleration phase when the mass of the official handball ball was increased by a 75%. This result could be explained by the increase in the impulse necessary to stop the backward movement of the ball. In this sense, previous investigations examining vertical jumps have confirmed that, when the braking impulse is very high, the coupling time between the eccentric and concentric phase increases, which implies a decrease in elastic muscular participation and, consequently, a reduction in the subsequent accelerative impulse.[30,31] The analysis of the horizontal force- and power-time curves with the Δ75% condition suggest changes in the structure of the movement, which confirm the findings of our previous investigation.[7] Future studies should elucidate whether using balls lighter than the official handball could also affect the structure of the movement. Furthermore, the addition of handballs lighter than the official ball could help in establishing the elastic profile of handball players as has been previously done for other multi-joint tasks such as the vertical jump.[32]

Practical applications

The use of balls overloaded in the range used in this study, increases the applied horizontal force and reduces the horizontal velocity of the ball. The power applied to the ball also shows a tendency to increase with the increment of the mass, but the differences were not significant until the mass of the ball was incremented by 75%. However, we should be cautious because the structure of the movement was altered during the Δ75% condition (i.e. maximum values of force and power were obtained farther from the instant of the release of the ball). Therefore, considering these data and the findings of previous research, specific resistance training with force overloads does not seem to be the most appropriate stimulus to improve throwing performance.

The decrement in velocity with the increment in the mass of the ball is explained because the force applied to the ball increases at a slower rate than the weight of the ball. The force applied likely increased at a similar rate as the time available for the involved muscles to produce force. This argument reinforces the relevance of increasing the rate of force development through an improvement in neural activation. The definitive rise of the force-time curve was delayed with respect to the beginning of the acceleration phase when the mass of the official ball was incremented by 75%. This fact could be explained by the high impulse needed to break the backward movement of the ball in an eccentric contraction which could be responsible for the lower elastic contribution to the force application during the acceleration phase. These arguments support the relevance of theories associated with the stretch-shortening cycle and plyometric training.

Declaration of conflicting interests

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