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Sex differences in competitive surfers' generic and specific strength capacity

AUTHORS: Iosu Fernandez-Gamboa[1], Javier Yanci[1], Cristina Granados[1], Bret Freemyer[2], Jesus Camara[1]

[1] Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Spain
[2] Department of Kinesiology and Rehabilitation Science, University of Hawaii, Manoa, Honolulu, Hawaii

Corresponding author:
Iosu Fernandez de Gamboa
Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country, UPV/EHU
Portal de Lasarte 71, 01007
Vitoria – Gasteiz, Spain
Phone: (+34) 654930050
Email: iosugamboa@gmail.com

ABSTRACT: To compare the pop-up and counter movement jump (CMJ) and to analyse the relationships among the variables between sexes and different ages [under (U16), over (O16) 16 years] in male and female competitive surfers. Eighty-three surfers were divided according to sex, male (n = 55) and female (n = 28), and to age, U16 (n = 47) and O16 (n = 36). Vertical jump and pop-up movements were measured through the vertical ground reaction force with a force plate. CMJ demonstrated that the O16 male group exhibited significantly greater force compared to females in the concentric phase of the jump (CMJ_{FMAX}) ($p < 0.01$, ES = 1.82, large). Female U16 and O16 groups presented increased unloading rates in the eccentric phase compared to male surfers (CMJ_{ULR}) ($p < 0.05$, ES = 0.73, moderate and $p < 0.05$, ES = 0.12, trivial, respectively). O16 males obtained significantly greater values than O16 females in the push-up phase (POP_{PUSH}) ($p < 0.05$, ES = 0.76, moderate). Moderate correlations were found between lower-body power capacity and the pop-up (r = 0.32; ± 0.16 CL, $p < 0.01$, 98.1/1.9/0, very likely, moderate). General and skill-specific strengths are different in competitive male and female surfers, dependent upon their age range. The moderate association between CMJ and pop-up suggests that the pop-up might be influenced by other factors such as coordination or upper-body strength. Therefore, competitive surfers should also train the upper body strength and overall coordination in order to improve the performance of the pop-up movement.

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INTRODUCTION

Due to the variety of different ocean conditions in which competitions take place, the surfer has to evaluate waves and adapt his or her movements to them [1]. The first movement performed during wave riding is the pop-up [2]. It consists of a rapid transition from lying prone to a standing position on the surfboard, when the wave begins to carry the surfer forward. The execution of the pop-up should not jeopardize the stability of the board, given that excessive forces would compromise its buoyancy. Thus, an efficient pop-up technique allows surfers to have better wave positioning, extended wave riding times, and increased potential to perform more manoeuvres [3]. The pop-up is broken down into three phases: push-up, leg movement and landing. Two previous investigations have examined vertical ground reaction forces of surfers during this sport-specific movement [2,3]. Eurich et al. [3] analysed kinetic parameters exerted by the arms only during the push-off phase. Recently, Parsonage et al. [2] analysed pop-up differences between male and female surfers' isometric and dynamic push-up strength and length of time from chest lift off to front foot contact. However, previous studies have not analysed the different phases of the pop-up in competitive surfers and how this may vary between sexes and with age. Although it is known that anthropometric characteristics [1] and physical conditioning [4] are different between male and female surfers, it is unknown how performance in the specific phases of the pop-up may differ between sexes.

Another important feature of competitive surfing is the general lower-body strength [5]. Previous research observed that higher ranked surfers had superior performance in counter movement jumps (CMJ) than lower ranked surfers [5], and elite competitive surfers who had competed in the Australian Nationals or World Junior Championships male junior surfers had higher vertical jump capacity (i.e., relative vertical jump peak force, vertical jump peak velocity, and vertical jump height) than non-elite surfers [6]. Consequently, strength and power capacities appear to play a significant role in surfing performance [6]. Nonetheless, these strength and power capacities have never been analysed in any research making a distinction between competitive male and female surfers. In addition, considering that manoeuvres are key elements to maximize scoring potential [7] and that the pop-up is the first movement that a surfer has to perform, it seems reasonable to look into the possible differences between male and female competitive surfers in CMJ vertical ground reaction forces and pop-up characteristics and whether a higher jump capacity can be associated with a better performance in the pop-up.

Considering the importance of the vertical ground reaction forces in describing the different phases of the pop-up technique and the lack of scientific literature analysing the vertical ground reaction force, the aims of this study are threefold: (a) to compare the parameters of the vertical ground reaction forces in the different pop-up phases (push-up, leg movement and landing) and in the different CMJ phases (push and landing), (b) to analyse the relationship between the parameters describing the pop-up phases and, (c) to represent the relationship of the vertical ground reaction forces of the pop-up and the CMJ in male and female competitive surfers.

MATERIALS AND METHODS

Participants

Eighty-three competitive male (n = 55) and female (n = 28) surfers participated in this study (18.13 ± 6.76 years, 168.75 ± 8.86 cm, 60.58 ± 9.97 kg, 20.63 ± 2.03 kg·m^{-2}). Data were collected during a surfing open division competition at a national level, during the "Euskaltel Euskal Zirkuitua" championship, hosted by the Basque Country Surfing Association, as part of the open category three stops tour. The athletes were divided according to sex (male and female) and according to their surfing age division [under (U16) (n = 47) and over (O16) (n = 36) 16 years] (Table 1). Participants received a clear explanation of the study, including the risks and benefits of participation, and completed informed consent documents. Moreover, underage participants' written informed consent was required from their legal guardian or parent. The study and its procedures were approved by the institutional review board, met the ethical standards in Sport and Exercise Science Research [8] and were performed in accordance with the Declaration of Helsinki (2013).

Procedures

Anthropometric Characteristics: Participants' stature (cm) was measured with a stadiometer (Holtain Ltd., Crymych, United Kingdom) fixed to the wall and recorded to the nearest 0.1 cm [9]. Body mass (kg) was measured with an electronic scale to the nearest 0.1 kg (Fagor, BB-150, Mondragon, Spain). The body mass index (BMI) was calculated from stature and body mass.

Vertical Jump: Participants performed three counter movement jump (CMJs) interspersed with 45 s recovery periods [10]. The best output of the three jumps was considered for statistical analysis. The CMJ had to be performed with their hands on their hips during the entire jumping activity [11]. The maximal flexion of the knees during this

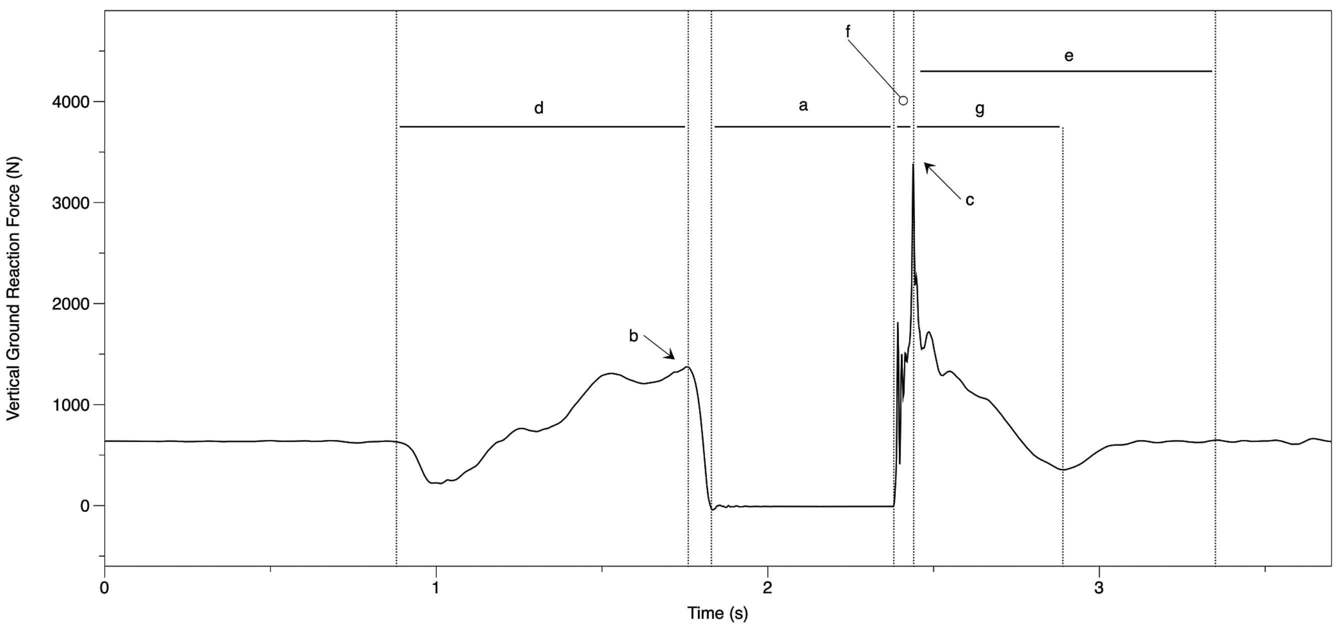

FIG. 1. Vertical ground reaction force (VGRF) over time (in seconds) during a CMJ. Values presented are an example of one competitive surfer.
(a) CMJ_{FT} = counter movement jump flight time; (b) CMJ_{FMAX} = counter movement jump maximal force; (d) CMJ_{T1} = counter movement jump time one; (f) CMJ_{LR} = counter movement jump loading rate; (g) CMJ_{ULR} = counter movement jump unloading rate; (c) CMJ_{F1} = counter movement jump force one; (e) CMJ_{TTS} = counter movement jump time to stabilization.

TABLE 1. Participants' description according to sex (male and female), and according to age (U16 and 016).

	All (n = 83)			U16 (n = 47)		016 (n = 36)	
	Total sample	Female (n = 28)	Male (n = 55)	Female (n = 15)	Male (n = 32)	Female (n = 13)	Male (n = 23)
Age (yr)	18.13 ± 6.75	15.75 ± 2.99	19.35 ± 7.77	13.47 ± 2.17	14.41 ± 1.07	18.38 ± 0.77	26.22 ± 7.86
Mass (kg)	60.57 ± 9.96	54.82 ± 7.00	63.51 ± 10.02	51.93 ± 8.57	58.69 ± 10.07	58.15 ± 1.46	70.22 ± 4.77
Stature (cm)	168.74 ± 8.85	161.79 ± 3.15	172.29 ± 8.73	160.20 ± 2.11	168.38 ± 8.98	163.62 ± 3.23	177.74 ± 4.51
BMI ($kg\cdot m^{-2}$)	21.10 ± 1.93	20.90 ± 2.26	21.20 ± 1.76	20.17 ± 2.87	20.50 ± 1.68	21.74 ± 0.65	22.17 ± 1.38

U16 = under 16 years; O16 = over 16 years; BMI = body mass index.

phase was required to be approximately 90º [12]. Any jump that did not meet the considered requirements was excluded from the calculations and it had to be repeated. The variables were obtained through a force plate (Kistler, Quattro Jump; Winterthur, Switzerland). Flight time (CMJ_{FT}) and maximal force (CMJ_{FMAX}) of the jump were obtained and the maximal peak force (CMJ_{F1}) during the landing phase was recorded (Figure 1). For the temporal data, the time to production of CMJ_{FMAX} (CMJ_{T1}) and the time to stabilization (CMJ_{TTS}) were calculated [13–15]. CMJ_{TTS} was determined during the landing phase, beginning with the first contact of the feet with the ground and ending when the vertical ground reaction force (VGRF) reached and stayed within 5% of the subject's body weight [16]. The peak loading rates of the landing phase were determined (CMJ_{LR}), as calculated by the ratio between the magnitude of CMJ_{F1} and the time elapsed from the initial contact of the feet with the ground at the landing phase to the production of these peaks [16]. Similarly, the unloading rate of the landing phase (CMJ_{ULR}) was determined, as calculated by the ratio between the time elapsed from CMJ_{T1} to the production and magnitude of the minimum peak produced after the initial contact of the feet with the ground at the landing phase before the CMJ_{TTS} [16]. CMJ_{FMAX} and CMJ_{F1} were normalized according to the subjects' body weight (BW). CMJ_{LR} and CMJ_{ULR} were normalized according to the participants' body mass ($BW\cdot s^{1}$).

FIG. 2. Experimental set up of the pop-up movement.

Pop-Up: A pop-up was performed over a force platform (Kistler, Quattro Jump; Winterthur, Switzerland) to measure the VGRF during the pop-up execution [3]. Surfers performed three trials interspersed with 45 s recovery periods [10]. The trial where the output of the graph representing the VGRF clearly showed the different phases of pop-up was taken into account for future analysis. That is, the push-up phase peak was represented and the leg movement phase showed a minimum peak. Also when in the landing phase the maximum and minimum peaks were clearly differentiated from each other. Participants were prone on the floor with their chest and shoulders centred over the force platform. Both hands were placed on the force plate with thumbs in line with the armpits. They performed the pop-up movement by straightening their arms explosively and as quickly as possible to lift their body from the push-up position to the squat stance, with both feet under the hips [3].

The push-up phase begins when the surfer starts pushing the force plate with his hands until the VGRF returns to the surfer's bodyweight. During this phase, there is a VGRF peak that corresponds to the maximum force exerted against the force plate (POP_{PUSH}).

From the temporal data, the time to production of POP_{PUSH} (POP_{TTPU}) was obtained. After the VGRF peak the surfer kept lifting the body from a prone position moving upwards, until the VGRF dropped to become equal to the participant's body weight; the elapsed time to this point from the POP_{PUSH} was obtained as time one (POP_{T1}). During the leg movement phase, the VGRF drops below body weight while the surfer is moving upwards. The legs move forward from the back position of the board, the feet are placed on the surfboard and the minimal force is applied (POP_{LMF}). During this last phase, the elapsed time as the subject bodyweight is reached in the VGRF to POP_{LMF} was obtained as time two (POP_{T2}). Finally, the landing phase occurs when the VGRF increases from the first contact of one foot on the surfboard. The time elapsed from POP_{LMF} until the subject's body weight is again reached again in the VGRF was calculated as time three (POP_{T3}). The VGRF shows a sharp landing peak (POP_{REACH}); here the elapsed time as the subject body weight is reached in the VGRF until POP_{REACH} is produced was obtained as time four (POP_{T4}); afterward the surfer relaxes the leg and hip muscles, thus allowing the knees and hips to flex (POP_{RMF}). When the ground reaction force reached and stayed within 5% of the surfer's body weight [16], stabilization was also registered (POP_{TTS}). The loading rates of the peak of the push-up phase and the landing phase were calculated (POP_{LR1} and POP_{LR2}, respectively) by the ratio between the magnitude of POP_{PUSH} and POP_{REACH} and the time elapsed from the given initial force of the push phase and landing phase respectively to the production of these peaks [16]. The unloading rates of the push-up phase and the landing phase were calculated (POP_{ULR1} and POP_{ULR2} respectively), determined by the ratio between the time elapsed from POP_{PUSH} (Figure 2) and POP_{REACH} to the production and magnitude of the minimum peaks produced in the push-up phase POP_{LMF} (Figure 2) and the landing phase POP_{RMF} (16). POP_{PUSH}, POP_{REACH}, POP_{LMF} and POP_{RMF} were normalized according to the subjects' body weight (BW) and also POP_{LR1}, POP_{LR2}, POP_{ULR1} and POP_{ULR2} were normalized according to the subjects' body weight ($BW \cdot s^1$).

Statistical analysis

The results are presented as means ± standard deviation (SD). Variables were not normally distributed and did not satisfy the equality of variances according to the Kolmogorov-Smirnov test and Levene test, respectively. Therefore, the Mann-Whitney U test was used to compare CMJ and pop-up data between female and male groups in all categories. Further, percentage differences were determined for each case. Cohen's effect size (ES) was calculated to determine the differences for practical purposes, with the following criteria used to infer the magnitude of the difference: <0.2 (trivial), 0.2–0.5 (small), 0.5–0.8 (moderate), and >0.8 (large) [17]. The Spearman product-moment correlation coefficient (r) with 90% confidence limits (CL) [18] was calculated to determine the relationships among the parameters obtained from the CMJ and pop-up tests. The magnitude of correlation between analysed variables was assessed with the following thresholds: < 0.1, trivial; = 0.1–0.3, small; < 0.3–0.5, moderate; < 0.5–0.7, large; <0.7–0.9, very large; and <0.9–1.0, almost perfect [18]. Data analyses were performed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$.

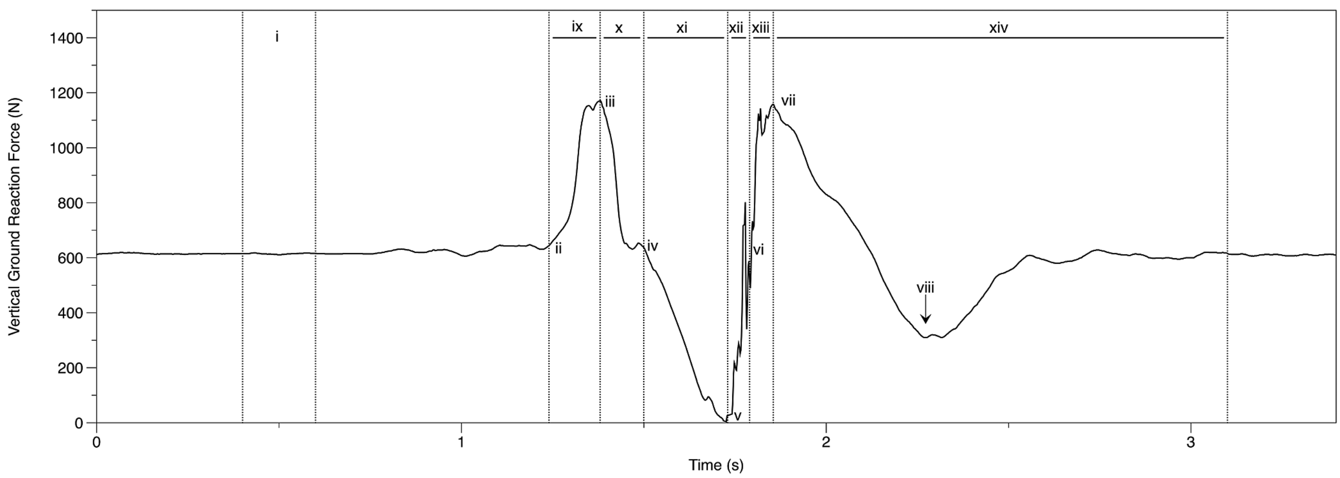

FIG. 3. Vertical ground reaction force (VGRF) over time in seconds during a pop-up movement. Values presented are an example of one competitive surfer.
i = initial VGRF is equal to the subject bodyweight, ii = push-up phase start, iii = pop-up push (POP_{PUSH}), iv = subject bodyweight in the VGRF is reached, v = pop-up leg movement minimal force (POP_{LMF}), vi = subject bodyweight in the VGRF is reached, vii = pop-up landing phase leg landing peak (POP_{REACH}), viii = pop-up landing phase minimal force (POP_{RMF}), ix = pop-up time to stabilization (POP_{TTS}), x = time to production of POP_{PUSH} (POP_{TTPU}), xi = pop-up time one (POP_{T1}), xii = pop-up time two (POP_{T2}), xiii = pop-up time three (POP_{T3}), xiv = pop-up time four (POP_{T4}).

RESULTS

Regarding the CMJ assessment among all competitive surfers (Table 2), the lone significant finding was that the males spent more time in the air than the females in CMJ_{FT} ($p < 0.01$, ES = 2.17, large). During the pop-up assessment, males pushed down with more kinetic force than the females during the POP_{PUSH} ($p < 0.01$, ES = 0.58, moderate) and spent more time unloading in POP_{ULR1} ($p < 0.01$, ES = 1.28, large). Conversely, the female group obtained significantly higher values in POP_{LMF} ($p < 0.05$, ES = 0.72, moderate) than the male group (Table 2).

Regarding the U16 groups (Table 3), the males again spent more time in the air, as seen in the CMJ_{FT} ($p < 0.01$, ES = 1.71, large). Kinetically during the pop-up, males spent more time unloading in POP_{ULR1} ($p < 0.01$, ES = 0.54, moderate) than females. In contrast, the females obtained significantly higher values in CMJ_{FMAX} ($p < 0.01$, ES = 0.46, small) and spent more time unloading in CMJ_{ULR} ($p < 0.05$, ES = 0.73, moderate) and in POP_{LMF} ($p < 0.05$, ES = 0.92, large) than the male group (Table 3).

Regarding the O16 group (Table 4), the male surfers obtained significantly higher values in CMJ_{FT} ($p < 0.01$, ES = 3.54, large), CMJ_{FMAX} ($p < 0.01$, ES = 1.82, large), POP_{PUSH} ($p < 0.05$, ES = 0.76, moderate), POP_{RMF} ($p < 0.01$, ES = 0.33, small), POP_{LR1} ($p < 0.01$, ES = 1.22, large) and POP_{ULR1} ($p < 0.01$, ES = 2.29, large) than the female group. Conversely, females obtained significantly higher values in CMJ_{ULR} ($p < 0.05$, ES = 0.12, trivial) and in POP_{LMF} ($p < 0.05$, ES = 0.33, small) than the male group (Table 4).

Examining the relationships between CMJ and the pop-up variables, significant correlations were found between CMJ_{FT} and POP_{LMF} (r = 0.48; ± 0.17 CL, $p < 0.01$, 99.9/0.1/0, most likely, moderate) and CMJ_{FT} and POP_{ULR1} (r = 0.26; ± 0.17 CL, $p = 0.02$, 92.6/7.4/0.1, likely, small). CMJ_{FMAX} was significantly correlated

TABLE 2. Counter movement jump (CMJ) and Pop-Up results among all competitive surfers and according to sex.

	All	Female	Male	Mean Dif. (%)	ES
CMJ					
CMJ_{FT} (s)	0.48 ± 0.05	0.44 ± 0.03	0.51 ± 0.04**	17.16	2.17
CMJ_{FMAX} (BW)	2.54 ± 1.35	2.72 ± 1.87	2.44 ± 1.00	-10.18	-0.15
CMJ_{T1} (s)	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.00	-28.50	-0.35
CMJ_{F1} (BW)	1.63 ± 0.67	1.51 ± 0.62	1.68 ± 0.68	10.90	0.26
CMJ_{LR} ($BW{\cdot}s^1$)	0.21 ± 0.11	0.21 ± 0.09	0.22 ± 0.12	27.00	0.61
CMJ_{ULR} ($BW{\cdot}s^1$)	0.31 ± 0.33	0.52 ± 0.57	0.23 ± 0.15	-45.39	-0.41
CMJ_{TTS} (s)	1.45 ± 0.88	1.64 ± 0.98	1.35 ± 0.81	-17.27	-0.29
Pop-Up					
POP_{PUSH} (BW)	1.39 ± 0.37	1.24 ± 0.38	1.47 ± 0.35**	18.22	0.58
POP_{REACH} (BW)	1.36 ± 0.30	1.37 ± 0.28	1.35 ± 0.31	-1.45	-0.07
POP_{TTPU} (s)	0.34 ± 0.15	0.34 ± 0.16	0.34 ± 0.14	1.55	0.03
POP_{TTS} (s)	0.66 ± 0.32	0.62 ± 0.35	0.68 ± 0.31	9.20	0.17
POP_{LMF} (BW)	0.24 ± 0.15	0.30 ± 0.15	0.19 ± 0.14**	-36.51	-0.72
POP_{RMF} (BW)	0.75 ± 0.22	0.76 ± 0.27	0.75 ± 0.19	-1.85	-0.05
POP_{LR1} ($BW{\cdot}s^1$)	0.46 ± 0.21	0.40 ± 0.18	0.50 ± 0.21	23.51	0.51
POP_{ULR1} ($BW{\cdot}s^1$)	0.19 ± 0.16	0.12 ± 0.09	0.24 ± 0.17**	98.76	1.28
POP_{LR2} ($BW{\cdot}s^1$)	0.23 ± 0.33	0.23 ± 0.43	0.24 ± 0.26	6.43	0.03
POP_{ULR2} ($BW{\cdot}s^1$)	0.36 ±0.35	0.39 ± 0.50	0.34 ± 0.25	-13.49	-0.11

Mean Dif. = Mean differences; ES = effect size; CMJ_{FT} = Counter movement jump flight time; CMJ_{FMAX} = Counter movement jump maximal force; CMJ_{T1} = Counter movement jump time one; CMJ_{F1} = Counter movement jump force one; CMJ_{LR} = Counter movement jump loading rate; CMJ_{ULR} = Counter movement jump unloading rate; CMJ_{TTS} = Counter movement jump time to stabilization; POP_{PUSH} = Pop-Up push-up; POP_{REACH} = Pop-Up reach; POP_{TTPU} = Pop-Up time to production of push-up; POP_{TTS} = Pop-Up time to stabilization; POP_{LMF} = Pop-Up leg movement minimal force; POP_{RMF} = Pop-Up reach minimal force; POP_{LR1} = Pop-Up loading rate one; POP_{ULR1} = Pop-Up unloading rate one; POP_{LR2} = Pop-Up loading rate two; POP_{ULR2} = Pop-Up unloading rate two.

**$p < 0.01$ significant differences with female group.

TABLE 3. Counter movement jump (CMJ) and Pop-Up results among all under 16 years (U16) category competitive surfers and according to sex.

	U16 (All)	Female	Male	Mean Dif. (%)	ES
CMJ					
CMJ_{FT} (s)	0.49 ± 0.05	0.43 ± 0.03	0.49 ± 0.06**	13.79	1.71
CMJ_{FMAX} (BW)	2.57 ± 1.57	2.96 ± 1.40	2.31 ± 0.76**	-21.87	-0.46
CMJ_{T1} (s)	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	4.00	0.05
CMJ_{F1} (BW)	1.67 ± 0.62	1.49 ± 0.66	1.79 ± 0.68	20.51	0.46
CMJ_{LR} ($BW·s^1$)	0.28 ± 0.12	0.23 ± 0.07	0.21 ± 0.12	-9.15	-0.28
CMJ_{ULR}($BW·s^1$)	0.41 ± 0.45	0.41 ± 0.34	0.16 ± 0.08*	-60.55	-0.73
CMJ_{TTS} (s)	1.51 ± 0.91	1.43 ± 1.08	1.46 ± 0.86	2.21	0.03
Pop-Up					
POP_{PUSH} (BW)	1.33 ± 0.29	1.34 ± 0.20	1.40 ± 0.33	5.06	0.33
POP_{REACH} (BW)	1.37 ± 0.33	1.46 ± 0.23	1.33 ± 0.28	-9.40	-0.59
POP_{TTPU} (s)	0.32 ± 0.15	0.30 ±0.20	0.30 ± 0.20	2.59	0.04
POP_{TTS} (s)	0.66 ± 0.35	0.57 ± 0.40	0.61 ± 0.25	7.23	0.10
POP_{LMF} (BW)	0.29 ± 0.16	0.40 ± 0.19	0.22 ± 0.12*	-44.67	-0.92
POP_{RMF} (BW)	0.76 ± 0.25	0.80 ± 0.18	0.74 ± 0.24	-7.49	-0.33
POP_{LR1} ($BW·s^1$)	0.42 ± 0.20	0.40 ± 0.26	0.42 ± 0.18	4.73	0.07
POP_{ULR1} ($BW·s^1$)	0.18 ± 0.16	0.13 ± 0.10	0.19 ± 0.13**	42.15	0.54
POP_{LR2} ($BW·s^1$)	0.24 ± 0.39	0.09 ± 0.07	0.13 ± 0.20	33.23	0.44
POP_{ULR2} ($BW·s^1$)	0.38 ± 0.41	0.37 ± 0.37	0.31 ± 0.30	-16.76	-0.17

Mean Dif. = Mean differences; ES = effect size; CMJ_{FT} = Counter movement jump flight time; CMJ_{FMAX} = Counter movement jump maximal force; CMJ_{T1} = Counter movement jump time one; CMJ_{F1} = Counter movement jump force one; CMJ_{LR} = Counter movement jump loading rate; CMJ_{ULR} = Counter movement jump unloading rate; CMJ_{TTS} = Counter movement jump time to stabilization; POP_{PUSH} = Pop-Up push-up; POP_{REACH} = Pop-Up reach; POP_{TTPU} = Pop-Up time to production of push-up; POP_{TTS} = Pop-Up time to stabilization; POP_{LMF} = Pop-Up leg movement minimal force; POP_{RMF} = Pop-Up reach minimal force; POP_{LR1} = Pop-Up loading rate one; POP_{ULR1} = Pop-Up unloading rate one; POP_{LR2} = Pop-Up loading rate two; POP_{ULR2} = Pop-Up unloading rate two.

* $p < 0.05$. **$p < 0.01$ significant differences with female group.

with POP_{PUSH} (r = 0.32; ± 0.16 CL, $p < 0.01$, 98.1/1.9/0, very likely, moderate), POP_{REACH} (r = 0.29; ± 0.17 CL, $p < 0.01$, 96.2/3.8/0, very likely, small) and POP_{RMF} (r = 0.38; ± 0.16 CL, $p < 0.01$, 99.6/0.4/0, most likely, moderate). Also, significant correlations were found for CMJ_{F1} with POP_{REACH} (r = 0.30; ± 0.17 CL, $p < 0.01$, 96.5/3.5/0, very likely, moderate) and with POP_{LR2} (r = 0.23; ± 0.18 CL, $p = 0.03$, 87.4/12.4/0.2, likely, small). Finally, a significant relationship was found between CMJ_{ULR} and POP_{RMF} (r = 0.23; ± 0.17 CL, $p = 0.03$, 88.4/11.4/0.1, likely, small).

Examining the relationships between the pop-up variables yielded large correlations between POP_{TTPU} and POP_{LR1} (r = 0.72; ± 0.09 CL, $p < 0.01$, 0/0/0, most likely, very large) and POP_{TTPU} and POP_{ULR1} (r = 0.59; ± 0.12 CL, $p < 0.01$, 0/0/0, most likely, large) (Figure 3B). Additionally, significant relationships between POP_{LR2} and POP_{REACH} (r = 0.52; ± 0.14 CL, $p < 0.01$, 0/0/0, most likely, large) and POP_{LR2} and POP_{LMF} (r = 0.52; ± 0.16 CL, $p < 0.01$, 0/0/0, most likely, large) were observed. Lastly, significant correlations were found between POP_{LR1} and POP_{ULR1} (r = 0.59; ± 0.12 CL, $p < 0.01$, 0/0/0, most likely, large), and between POP_{ULR2} and POP_{TTS} (r = 0.74; ± 0.08 CL, $p < 0.01$, 0/0/0, most likely, very large).

DISCUSSION

The results of the present study showed that males had higher values in CMJ_{FT} (17.16% in all participants, 13.79% in U16, and 19.68% in O16) than females. These findings are similar to previous research, in which males were found to have higher eccentric and concentric strength and power and greater peak power during the concentric phase of the CMJ compared to females [19,20]. Taking into account that surfing is practised under the same environmental conditions and the sport-specific requirements are the same for both sexes,

TABLE 4. Counter movement jump (CMJ) and Pop-Up variables among older 16 years (O16) competitive surfers according to sex.

	O16 (All)	Female	Male	Mean Dif. (%)	ES
CMJ					
CMJ_{FT} (s)	0.48 ± 0.05	0.43 ± 0.02	0.51 ± 0.03**	19.68	3.54
CMJ_{FMAX} (BW)	2.49 ± 1.02	2.13 ± 0.28	2.65 ± 1.00*	24.01	1.82
CMJ_{T1} (s)	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	-37.31	-0.47
CMJ_{F1} (BW)	1.58 ± 0.72	1.47 ± 0.59	1.48 ± 0.74	0.54	0.01
CMJ_{LR} ($BW{\cdot}s^{1}$)	0.18 ± 0.11	0.15 ± 0.10	0.17 ± 0.09	12.00	0.18
CMJ_{ULR}($BW{\cdot}s^{1}$)	0.26 ± 0.21	0.27 ± 0.36	0.23 ± 0.13*	-16.23	-0.12
CMJ_{TTS} (s)	1.37 ± 0.83	1.69 ± 0.99	1.40 ± 0.86	-17.33	-0.30
Pop-Up					
POP_{PUSH} (BW)	1.47 ± 0.45	1.21 ± 0.53	1.62 ± 0.22**	33.66	0.76
POP_{REACH} (BW)	1.35 ± 0.26	1.30 ± 0.30	1.45 ± 0.22	11.64	0.49
POP_{TTPU} (s)	0.37 ± 0.15	0.33 ± 0.13	0.38 ± 0.13	15.45	0.37
POP_{TTS} (s)	0.66 ± 0.29	0.68 ± 0.37	0.70 ± 0.28	3.37	0.06
POP_{LMF} (BW)	0.19 ± 0.13	0.24 ± 0.07	0.16 ± 0.16*	-31.00	-0.99
POP_{RMF} (BW)	0.74 ± 0.18	0.72 ± 0.20	0.79 ± 0.13*	9.19	0.33
POP_{LR1} ($BW{\cdot}s^{1}$)	0.53 ± 0.21	0.38 ± 0.18	0.60 ± 0.20*	56.66	1.22
POP_{ULR1} ($BW{\cdot}s^{1}$)	0.21 ± 0.16	0.09 ± 0.07	0.26 ± 0.12*	167.24	2.29
POP_{LR2}($BW{\cdot}s^{1}$)	0.23 ± 0.21	0.19 ± 0.14	0.31 ± 0.27	55.78	0.76
POP_{ULR2} ($BW{\cdot}s^{1}$)	0.33 ± 0.26	0.28 ± 0.25	0.43 ± 0.39	50.24	0.57

Mean Dif. = Mean differences; ES = effect size; CMJ_{FT} = Counter movement jump flight time; CMJ_{FMAX} = Counter movement jump maximal force; CMJ_{T1} = Counter movement jump time one; CMJ_{F1} = Counter movement jump force one; CMJ_{LR} = Counter movement jump loading rate; CMJ_{ULR} = Counter movement jump unloading rate; CMJ_{TTS} = Counter movement jump time to stabilization; POP_{PUSH} = Pop-Up push-up; POP_{REACH} = Pop-Up reach; POP_{TTPU} = Pop-Up time to production of push-up; POP_{TTS} = Pop-Up time to stabilization; POP_{LMF} = Pop-Up leg movement minimal force; POP_{RMF} = Pop-Up reach minimal force; POP_{LR1} = Pop-Up loading rate one; POP_{ULR1} = Pop-Up unloading rate one; POP_{LR2} = Pop-Up loading rate two; POP_{ULR2} = Pop-Up unloading rate two.

* $p < 0.05$. **$p < 0.01$ significant differences with female group.

female surfers displayed lower strength in the lower body than males. Interestingly, one of the main findings of this study was the number of differences between sexes when separated by age groups. Males who were O16 had greater CMJ_{FT} (19.68%) and $CMJF_{MAX}$ (24.01%) than females, but surprisingly we found that U16 female competitive surfers obtained superior values in the $CMJF_{MAX}$ than the males (21.87%) when normalized by body mass. It has been reported that earlier maturity in female junior athletes afforded advantages in measures of strength/power compared to male athletes [21,22]. In this case male U16 surfers are reported to be taller and heavier than female surfers, suggesting that female surfers' maturity may not play an important role as suggested in other studies [21,22], and seems to point to a greater maturation on the part of the male surfers, which however does not manifest in an increase of the $CMJF_{MAX}$. These differences are worthy of further investigation, yet should be interpreted with caution.

During the CMJ's landing phase, both U16 and O16 female athletes presented lower CMJ_{ULR} compared to their male counterparts (60.55% and 16.23%, respectively). These values in female surfers might suggest that they are likely to have better capabilities to attenuate the landing eccentric load, which could be a positive aspect to performance in surfing.

The pop-up is a specific and highly technical movement to perform for optimal wave riding (2,3). The results of our study indicated that male athletes showed higher values than female athletes in POP_{PUSH} in the "All" category (18.22%) and in the O16 category (33.66%), as previously described by Eurich et al. [3]. However, no differences were observed in POP_{PUSH} between U16 male and female athletes. These differences are likely due to the greater upper body strength of male surfers [3], but are not yet differentiated in the U16 competitive surfers.

During the pop-up phase, surfers are required to move ~75% of their body weight in less than a second, and therefore high levels of upper-body force production within a time constraint are critical for success [2]. In our study, the loading rate during the push-up phase was observed to be higher (56.66%) in O16 male surfers than in female surfers. This may allow for the male surfers to perform the push-up phase faster, in order to stand on the surfboard to gain a better wave position.

Male competitive surfers in all participants, O16 and U16 categories, showed greater values (42.15 - 167.24%) than female surfers in the POP_{ULR1}. This higher POP_{ULR1} rate may be explained by their higher POP_{LR}, suggesting that in consequence they needed to rapidly attenuate the force by quickly unloading the force applied by the upper body while transitioning between positions on the surfboard. Male surfers were shown to have lower values (9.19%) than female surfers in the POP_{RMF}. Such lower value in the POP_{RMF} allowed male surfers to maintain stability on the surfboard without losing control over it. In the current study, female athletes showed greater values than male surfers in POP_{LMF}, in all the participants (36.51%), in the U16 category (44.67%) and in the O16 category (31.00%). As female surfers do not apply as much force as the males in the push-up phase, they do not have to attenuate that greater force, making the leg movement smoother and with a greater POP_{LMF}. Therefore, it may be important in the pop-up to measure not only the push phase, but also the landing phase, as both can be relevant in competitive surfing performance.

Another objective of the current research was to determine the correlations between the lower-body strength measures of the CMJ and the ability to perform a specific movement such as the pop-up in an attempt to determine whether the pop-up is influenced by the muscle strength of the lower body. Some significant associations have been found between the CMJ and the pop-up in both concentric and eccentric phases, but these associations are either small or moderate (r = 0.30 – 0.48). Although there seems to be some association between jumping (CMJ) and pop-up, the small or moderate correlations found lead us to think that they are two independent abilities. Accordingly, the pop-up is an action that can be influenced by lower-body strength, upper-body strength, coordination, and other aspects [2,3]. Therefore, competitive surfers should not only train the lower-body strength, but also other skills that may influence the performance of the pop-up movement.

Previous studies have analysed the push-up movement in the pop-up [2,3], but the novelty of this article is the description of the discrete phases of the pop-up. Our results demonstrate that POP_{TTPU} had a significant correlation with POP_{LR1} (Figure 3A) and POP_{ULR1} (Figure 3B). Also, correlations were found between POP_{LR1} and POP_{ULR1} (Figure 3E). The relationship of POP_{TTPU} with POP_{LR1} and POP_{ULR1} indicates that an explosive push-up produced in a shorter time will generate higher loading and unloading rates. It stands to reason that the ability to have greater upper-body explosive power will enable surfers to launch themselves into a quicker pop-up. Additionally, significant relationships between POP_{LR2} with both POP_{REACH} (Figure 3C) and POP_{LMF} (Figure 3D) were observed. A higher peak in the POP_{LMF} will generate a more explosive POP_{LR2}, as leg muscles and joints will not have to attenuate high landing force peaks, gaining more control of the surfboard in a smoother pop-up movement. In the same way, a high POP_{LR2} will generate a high impact peak in the POP_{REACH}. Therefore, lower peak values will benefit the surfer in the landing phase, generating lower POP_{REACH} peaks and higher POP_{LMF}, allowing the surfer to gain more control of the surfboard without disturbing their buoyancy. Finally, significant relationships between POP_{ULR2} and POP_{TTS} were found. A higher POP_{ULR2} indicates that the athlete has to attenuate higher landing impact forces for a longer time, requiring more POP_{TTS}, in order to maintain control over the surfboard.

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