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Original research

The influence of winter vitamin D supplementation on muscle function and injury occurrence in elite ballet dancers: A controlled study

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ABSTRACT

Objectives: Athletes who train indoors during the winter months exhibit low serum 25-hydroxyvitamin D [25(OH)D] concentrations due to a lack of sunlight exposure. This has been linked to impaired exercise performance. The purpose of this study was to assess the effects of oral vitamin D₃ supplementation on selected physical fitness and injury parameters in elite ballet dancers.

Design: Controlled prospective study.

Methods: 24 elite classical ballet dancers (intervention $n = 17$; control $n = 7$) participated in a controlled 4-month oral supplementation of vitamin D₃ (2000 IU per day). Isometric muscular strength and vertical jump height were measured pre and post intervention. Injury occurrence during the intervention period was also recorded by the in-house medical team. Repeated measures ANOVA and Mann–Whitney–U statistical tests were used and significance was set at $p \leq 0.05$.

Results: Significant increases were noted for the intervention group for isometric strength (18.7%, $p < 0.01$) and vertical jump (7.1%, $p < 0.01$). The intervention group also sustained significantly less injuries than the controls during the study period ($p < 0.01$).

Conclusions: Oral supplementation of vitamin D₃ during the winter months has beneficial effects on muscular performance and injury occurrence in elite ballet dancers.

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1. Introduction

Significant variations in serum 25-hydroxyvitamin D [25(OH)D] concentrations have been found in the general population.¹ Similar patterns have also been reported in relation to athletic populations; almost 80% of Australian gymnasts had insufficient levels of serum 25(OH)D, while 12.5% and 44% of adolescent male dancers from the same country were found to have deficient and insufficient levels of this same vitamin, respectively.^{2,3} Training in-doors has also a negative effect on serum 25(OH)D levels with insufficiencies reaching up to 80% compared to 48% in those training out-doors.⁴ However, it has been reported that, in elite dancers, serum 25(OH)D levels are subject to seasonal variations where summer months have been linked with clinically and statistically significantly higher vitamin

D concentrations (22.9 ± 9.51 ng/ml) compared to winter months (14.4 ± 4.85 ng/ml).⁵

Although dance is fundamentally different from sport in that its goals are artistic rather than competitive, there is a link between physical fitness levels and artistic ability.^{6,7} Dancers need to be able to execute highly technical movements during high intensity intermittent exercise with dance periods during class and performance lasting between 1 and 6 min followed by rest periods of 2–9 min.⁸ Dancers also demonstrate high incidence of injury which has been partly attributed to inadequate levels of physical fitness,⁹ particularly by low levels of muscular strength¹⁰ and aerobic capacity.¹¹

Serum 25(OH)D is an important hormone with a wide range of functions¹; its deficiency has been shown to impair muscle action¹² and skeletal mineralization,¹³ and can lead to sarcopenia and the resulting decrease in muscle strength,¹⁴ particularly in the elderly to whom most of the published work refers to. Bischoff et al.¹⁵ reaffirmed the importance of exposure to sunlight on serum 25(OH)D levels, where institutionalized elderly demonstrated lower sunlight

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exposure and lower muscle strength compared to controls. Holick¹ and Hamilton¹⁶ have noted that serum 25(OH)D deficiency is now prevalent across ages, with significant negative relationships between serum 25(OH)D status and lower body power, performance¹⁷ and grip strength¹⁸ in adolescent girls.

An early systematic review on the elderly, concluded that vitamin D₃ supplementation alone improves physical performance and, in combination with calcium, could result in reduced falls.¹⁹ These findings are partly supported by more recent work, which included a number of random controlled trials, that revealed a positive effect on muscle function with vitamin D₃ supplementation in the elderly, although other studies disagree.²⁰ Wang and DeLuca²¹ suggested that the role of vitamin D on muscle function might be indirect as they could not detect the vitamin D receptor in skeletal muscle.

There has been little research on the potential benefits of vitamin D₃ supplementation on young, active individuals. This is particularly the case with dancers who not only are prone to serum 25(OH)D deficiency during winter months,^{2–5} but they also spend 6–8 h training in-doors 6 days a week throughout the year, with little exposure to direct sunlight. It should be noted that winter sunlight is normally insufficient for generating optimum levels of vitamin D₃ (cholecalciferol) from pre-vitamin D₃,²² while dietary intake of vitamin D, either cholecalciferol (vitamin D₃ through oily fish and dairy products) or ergocalciferol (vitamin D₂ through plant extracts to meet the vitamin D needs in both children and adults). Therefore, the aim of the present study was to examine the effect of vitamin D₃ supplementation during winter months on muscle function and injury occurrence in a group of elite ballet dancers.

2. Methods

Volunteers: Twenty-four professional caucasian dancers on full-time dance contracts were recruited from a single international touring ballet company of 58 dancers. They were involved in 6–8 h of dancing per day, 38 h per week, which included no direct strength or power training. The participants reported that they had not taken supplementary vitamins or traveled overseas in the past 3 months. During the previous year, serum 25(OH)D from the same dancers were monitored during the winter and summer months. These data revealed that all the dancers had either insufficient (10–30 ng/ml) or deficient (<10 ng/ml) 25(OH)D levels during winter and only 15% of the cohort achieving normal levels post summer holidays.⁵ Based on these findings the authors recognized that it was clinically prudent for all participants to receive Vit D supplementation, and that the only way to form the necessary control group was to ask for volunteers. The latter agreed that they would receive the Vit D supplementation at the end of the study period. For the purpose of the current study, seven participants volunteered for the control group (male: $n=2$, 28 ± 0.00 yrs, 1.79 ± 0.02 m, 66.5 ± 0.42 kg; female: $n=5$, 27 ± 5.46 yrs, 1.64 ± 0.02 m, 50.7 ± 6.48 kg), while the intervention group consisted of 17 volunteers (male: $n=9$, 29 ± 6.76 yrs, 1.77 ± 0.08 m, 65.8 ± 11.24 kg; female: $n=8$, 28 ± 3.19 yrs, 1.64 ± 0.03 m, 49.0 ± 6.01 kg). Independent *t*-tests determined there were no significant differences for age, height and weight between the two groups. The dancers were exposed to 532 h of dance (dance class, rehearsal and performances) during the intervention period. As the dancers were all from the same company, activity levels between the two groups were considered homogeneous; workloads were found to be 2.2 ± 1.54 METs using Sensewear armbands with no significant differences between groups, genders or company position (2×3 factorial ANOVA), while work time was controlled by a universal union contract. Participant consent was obtained before testing began. The research protocol was approved by the lead author's university Ethics Review Committee.

Data collection: Data collection occurred at a latitude of $52^{\circ}29'N$ during the months of January to May (55.0–198.1 h of sunlight per month). Each participant completed a lifestyle questionnaire that covered menstrual history, oral contraception, medication, overseas travel and activity levels. The following parameters were assessed.

Muscular strength: A 5-s isometric quadricep contraction was used as a measure of muscle strength of the dominant leg. Participants were seated on a custom-made isometric strength chair with the test leg extended to an angle of 110° at the knee. A cuff was placed 4 cm above the lateral malleolus with a steel cable leading to a load cell (LCM Systems Ltd., UK) and the signal processed by PowerLab (AD Instruments, UK). Participants were given 5 familiarization trials prior to 3×5 -s maximal contraction testing. Verbal encouragement was given through all trials along with visual feedback from the computer monitor; the highest score was recorded.

Muscular power: A standing vertical jump was used to measure lower body muscle power. Participants were barefoot and were asked to assume the dance 1st position (heels together and hips externally rotated) on a jump meter (Takei Yashiroda, Japan); they were then instructed to perform a *demi-plié* (half-squat) and immediately jump as high as possible keeping heels together, hips externally rotated and pointed feet; the arms remained at the side throughout the jump sequence. Participants were asked to repeat the test three times and the highest score was recorded.

Injury reporting: A time-loss definition of injury was used whereby “any injury that prevented a dancer from taking a full part in all dance related activities that would normally be required of them for a period equal to or greater than 24 h after the injury was sustained”.²³ Injuries were reported by one of the 3 full-time in-house physiotherapists on a standardized injury reporting form. The total number of injuries sustained by the participants over the four month intervention period were recorded using the Orchard Sports Injury Classification System and injury severity was grouped as transient (return within 7 days), mild (return within 7–28 days), moderate (return within 29–84 days) and severe (return after 84 days).²³

Vitamin supplementation: The intervention group was provided with a daily dose of 2000 IU of vitamin D in tablet form over a 4-month period.

Statistical analyses: Isometric strength and vertical jump performances were analyzed using a 3-way ANOVA with repeated measures, the two between-subject factors being “group” (intervention vs. control) and “gender”, and the within-subject factor being “time” (pre vs. post intervention); 95% confidence intervals for all mean differences together with measures of effect size were also calculated using Partial Eta Squared. The frequency of injury was compared between groups (intervention vs. control) using a non-parametric Mann–Whitney *U* test. Significance was set at $p \leq 0.05$.

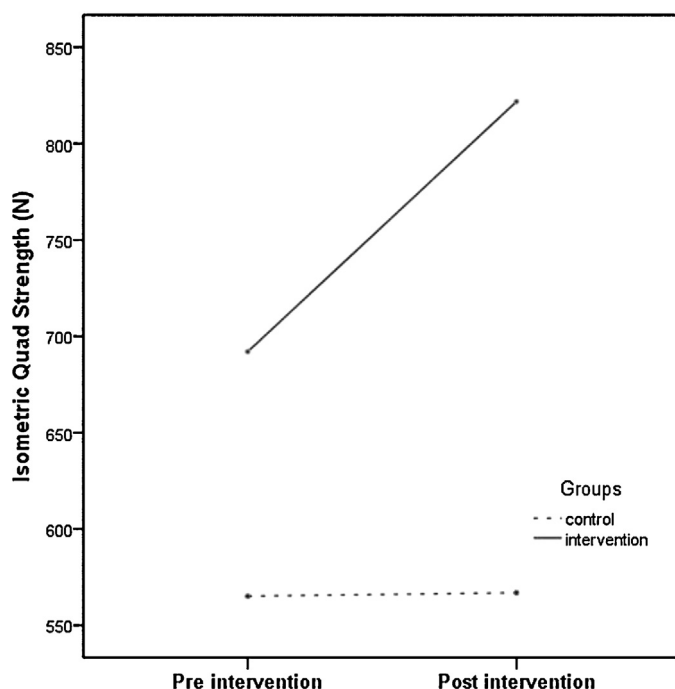
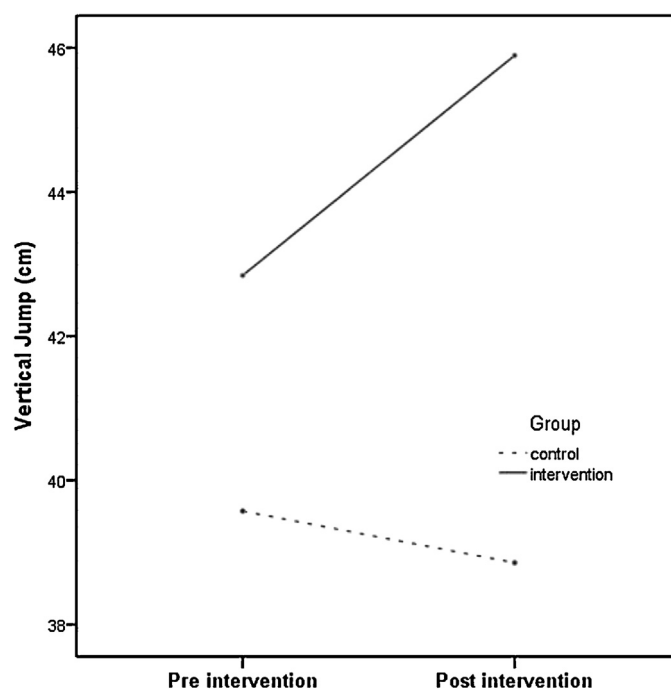
3. Results

The ANOVA of isometric strength identified significant main effects due to “gender” ($p < 0.001$) and “time” ($p = 0.01$) but most importantly a group-by-time interaction ($p = 0.030$), although the effect was small ($\eta^2 = 0.197$), as illustrated in Fig. 1 and Table 1. The differences (pre isometric strength – post isometric strength) were -1.79 N (95% CI was -143.98 to 140.39) for the controls, and -190.32 N (95% CI was -276.61 to -104.02) for the intervention group.

Very similar results were obtained for vertical jump performances (Table 1). The ANOVA identified significant main effects due to “gender” ($p < 0.001$) and “time” ($p = 0.010$) but as above a

Table 1Group and gender muscle function and injury data (mean $\pm$ SD).

Group	Gender	Strength (N)		Vertical jump (cm)		Injury occurrence
		Pre	Post	Pre	Post	
Intervention	Male (9)	918.6 $\pm$ 294.9	1055.0 $\pm$ 289.7	50.7 $\pm$ 8.7	54.0 $\pm$ 9.4	3
	Female (8)	286.5 $\pm$ 193.1	536.7 $\pm$ 134.5	34.1 $\pm$ 3.4	36.9 $\pm$ 3.1	2
	Group (17)	692.1 $\pm$ 363.7	821.9 $\pm$ 365.9**	42.8 $\pm$ 10.8	45.9 $\pm$ 11.2**	5**
Control	Male (2)	923.5 $\pm$ 140.0	889.5 $\pm$ 83.4	49.5 $\pm$ 7.8	50.5 $\pm$ 3.5	2
	Female (5)	421.8 $\pm$ 41.9	437.9 $\pm$ 35.9	35.6 $\pm$ 1.5	34.2 $\pm$ 2.2	5
	Group (7)	565.1 $\pm$ 253.1	566.9 $\pm$ 224.8	39.6 $\pm$ 7.6	38.9 $\pm$ 8.3	7

** Significant at $p < 0.01$.**Fig. 1.** Mean changes in isometric strength for the intervention and control groups.**Fig. 2.** Mean changes in vertical jump for the intervention and control groups.

group-by-time interaction ($p = 0.004$) with a moderate effect size ($\eta^2 = 0.322$), as illustrated in Fig. 2. The differences (pre vertical jump – post vertical jump) were 0.714 cm (95% CI was -0.93 to 2.36) for the controls, and -3.05 cm (95% CI was -4.05 to -2.06) for the intervention group.

Within the control group, 5 participants reported one injury, 1 participant two injuries and 1 no injury during the study period; while in the intervention group 12 reported no injuries and 5 one injury. In all cases the reported injuries were classified as muscle spasm/strain/tears and were “mild”²³ in nature with the dancers being excluded from dance activity for between 7 and 14 days (the lower end of the mild classification). The Mann–Whitney U analysis of injuries also identified a significantly higher number of injuries in the control (1.87/1000 h) compared to the intervention group (0.55/1000 h) ($p = 0.005$).

4. Discussion

The purpose of the present study was to examine the effects of vitamin D₃ supplementation during winter months on muscle function and injury occurrence in a group of elite dancers who spend the majority of their training time in-doors. The intervention group demonstrated significant increases for the performance

related parameters of isometric strength and vertical jump. This group also sustained significantly less injuries than their controls during the study period.

As sunlight exposure provides 80–90% of the serum 25(OH)D body stores,²⁰ athletes and dancers who train indoors during daylight, especially in the winter, are at risk of serum 25(OH)D deficiency.^{2–5} Observational studies have reported a positive correlation between vitamin D status and muscle function.^{3,4,17} In particular, two of these studies have shown improved isometric quadriceps strength after supplementation of 800 IU/day vitamin D₃ for 6 months²⁴ and 90,000 IU/month for 4 months,²⁵ though both participant populations were elderly and sedentary. In contrast, the present study's participants had a mean age of 26 ± 4.57 yrs (range 20–35 yrs) and were highly active, carrying out 6–8 h of dancing a day at an average of 2.2 ± 1.54 METs.²⁶

The present study revealed a significant increase of 19% in isometric quadriceps strength for the intervention group and no changes in the control; this is comparable to previously reported increases of 24%²⁵ and considerably greater than 8.5% found by Pfeifer et al.²⁴ These two studies and the present one reported similar relative increases in isometric strength per 1000 IU/day supplementation; 0.35%/1000 IU,²⁴ 0.31%/1000 IU present study,

and 0.26%/1000 IU.²² The extent that these observed improvements could be due to initial serum 25(OH)D status and/or the supplemental dose of vitamin D needs to be examined more closely.

Muscle power and strength are inextricably linked as both utilize fast-twitch fibers (type II). The 19% improvement of strength for the intervention group in this study was accompanied by a 7.2% improvement in power, though the control group reported a 2% decline in power and no change in strength. The difference in strength and power improvements could be due to how serum 25(OH)D interacts with the different muscle fibers. Previous vitamin D intervention studies have not measured both strength and power, and as the majority of the studies have used a maximal isometric contraction^{19,20} which utilizes both type I and type II fibers, the ability to differentiate between fiber types is impossible. The present study does raise the question that vitamin D supplementation might be more fiber specific than previously thought with the greater percentage increase in isometric strength (Types I and II fiber utilization) compared to vertical jump (Type II fiber utilization) suggesting that the Type I fibers have seen a greater improvement in their function than Type II fibers. Birge and Haddas²⁷ found that vitamin D supplementation increased ATP content in muscle cells. Simpson et al.²⁸ reported 3 possible mechanisms through which serum 25(OH)D could improve muscle function, through their receptors in muscle fibers. These were the control of serum calcium concentration, which has a direct effect on muscle contraction; the possible direct action on muscles to induce expression of specific genes (Ca⁺⁺ ATPase enzyme) thereby altering calcium handling by the muscle cell; and dividing myoblasts and inducing differentiation to multinucleated non-dividing myotubes.

It has been repeatedly reported that injury is a fact of dancers' life often with detrimental effects. In a period of 12 months, almost 50% of a large sample of professional dancers reported one to six days off action due to a musculoskeletal injury, with the lower back, pelvis, legs, knees and feet to be the most frequently injured sites.²³ The present study demonstrated that vitamin D₃ supplementation had a significant influence on injury occurrence with the intervention group recording less injuries than their counterparts in the control group. This finding could be due to the observed improvements in strength within the intervention group and fits well with the well documented link between muscular strength levels and injury occurrence within different populations²⁹ including dancers.¹⁰ Although the majority of the dancers in the control group reported a muscular injury during the study period, the time-off from training (7–14 days exclusion from dance activity during a 4-month period) was not sufficient to have a detraining effect on muscle strength.

It is reasonable to assume that the present results may have been influenced by methodological limitations such as the relatively low number of participants and the lack of proper randomization of these participants into groups. However, both were inevitable due to practical and ethical reasons. The relatively low number of participants resulted from the need to control for the dancers' workloads, as well as performance and travel schedules; the best way to achieve this objective was to use just one dance company, but, at the same time, limiting the potential number of volunteers. Similarly, the lack of randomization of our participants into the experimental and control groups was unavoidable and had an ethical background. Based on existing data from our laboratory, the current authors recognized that it was clinically prudent for all participants to receive vitamin D₃ supplementation. Consequently, the only way to form the necessary control group was to ask for volunteers, rather than randomizing the available dancers into the experimental and control groups.

5. Conclusion

Within the limitations of this study, it was concluded that vitamin D oral supplementation, in a population known to be at risk of deficiencies, has significant improvements on selected muscle function parameters and injury occurrence. Vitamin D supplementation should be considered during the winter, particularly for those training indoors such as ballet dancers.

Practical implications

- Athletes, who train indoors, especially during the winter, are prone to serum 25(OH)D deficiency.
- Coaches and medical staff should consider monitoring serum 25(OH)D levels in their athletes throughout the year and especially during the winter months.
- This study has highlighted the benefits of vitamin D supplementation on improving muscle function and injury occurrence.
- Research has not shown any benefits of serum 25(OH)D levels on performance beyond normal serum levels (30 ng/ml or 75 nmol/l) and therefore supplementation should be used to return athletes to these normal levels.

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