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Effect of 4 wk of deep water run training on running performance

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ABSTRACT

Bushman, B. A., M. G. Flynn, F. F. Andres, C. P. Lambert, M. S. Taylor, and W. A. Braun. Effect of 4 wk of deep water run training on running performance. *Med. Sci. Sports Exerc.*, Vol. 29, No. 5, pp. 694–699, 1997. The purpose of this study was to determine whether trained competitive runners could maintain on-land running performance using 4 wk of deep water run training instead of on-land training. Eleven well-trained competitive runners (10 males, 1 female; ages, 32.5 ± 5.4 yr; height, 179.8 ± 9.3 cm; weight, 70.4 ± 6.7 kg (mean ± SD)) trained exclusively using deep water run training for 4 wk. Subjects trained 5–6 $d \cdot wk^{-1}$ for a total of 20–24 sessions (mean ± SD, 22 ± 1.5 sessions). Instruction and practice sessions were conducted prior to the training period. Before and after the deep water run training, subjects completed a 5-km race on the treadmill using a computer based system, a submaximal run at the same absolute workload to assess running economy, and a combined lactate threshold and maximal oxygen consumption test. No significant differences were found for (mean ± SEM): 5-km run time (pre, 1142.7 ± 39.5 s; post, 1149.8 ± 36.9 s; $P = 0.28$), submaximal oxygen consumption (pre, 44.8 ± 1.2 $mL \cdot kg^{-1} \cdot min^{-1}$; post, 45.3 ± 1.5 $mL \cdot kg^{-1} \cdot min^{-1}$; $P = 0.47$), lactate threshold running velocity (pre, 249.1 ± 0.9 $m \cdot min^{-1}$; post, 253.6 ± 6.3 $m \cdot min^{-1}$; $P = 0.44$), or maximal oxygen consumption (pre, 63.4 ± 1.3 $mL \cdot kg^{-1} \cdot min^{-1}$; post, 62.2 ± 1.3 $mL \cdot kg^{-1} \cdot min^{-1}$; $P = 0.11$). Also no differences were found among Global Mood State pre-training, each week during training, and post-training. Competitive distance runners maintained running performance using 4 wk of deep water run training as a replacement for on-land training.

LACTATE THRESHOLD, MAXIMAL OXYGEN CONSUMPTION, RUNNING ECONOMY

Water exercise is a well-established technique in physical medicine and rehabilitation (24). One type of water exercise, deep water running (DWR), has become an attractive alternative to on-land running (OLR) for athletes with musculoskeletal injuries. Some runners are also replacing part of their OLR with DWR to reduce the risk of common overuse injuries (25). However, the lack of training specificity may be problematic and the transfer of deep water training to land-based exercise remains in question.

Researchers have examined physiologic responses to DWR such as oxygen consumption (3,7,19,20,22,28), cardiac output (28), heart rate (3,7,19,22,28), respiratory exchange ratio (3,7,19,22), ventilation (3,7), perceived exertion (3,19,20), and blood lactate concentrations (20,22). Although the physiological responses to DWR are of interest, information is needed regarding the impact of DWR on performance. Anecdotal reports have been used to suggest that OLR performance can be maintained or even improved using DWR training (2).

Research has focused on DWR as a training tool for untrained or recreationally active individuals, and the results have been equivocal (5,8,9,16,18). The effects of DWR have been examined in trained competitive runners, but racing performance was not assessed (23), although it was evaluated among recreationally active runners (8). Therefore, the purpose of this study was to determine if 4 wk of DWR, as a replacement for OLR, would enable runners to maintain OLR performance.

METHODS

Eleven competitive runners (10 males, 1 female) were recruited from the running community to participate (age 32.5 ± 6.7 yr, weight 70.4 ± 9.3 kg, height 179.8 ± 6.7 cm). The investigation was conducted from late October to early January to facilitate compliance and avoid major competitions. Subjects were recruited at a local road race and reported being at a reasonably high level of training immediately prior to the study. In the month preceding the study, subjects trained 4.3 ± 1.3 d and 43.2 ± 15.4 $km \cdot wk^{-1}$ (mean ± SD). All procedures were approved by the Human Subjects Research Review Committee (Research Project #93232) at The University of Toledo. All subjects gave written informed consent.

Each subject performed two practice sessions to become familiar with DWR prior to the start of the 4 wk of DWR training. Included in the practice sessions were an initial instructional session involving playing portions of a video tape on DWR technique (Deep Water Running Video: WET VEST, Bioenergetics, 1988) and instruction on proper form (6). Each subject wore a floatation device

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TABLE 1. Deep water run training workouts (6).

	Wk 1 and Wk 3	Total Exerc. Time (min)	Wk 2 and Wk 4	Total Exerc. Time (min)
Monday	5 × 2:00 @ RPE 3 8 × 1:00 @ RPE 4 5 × 2:00 @ RPE 3	28	10 × 1:30 @ 3–4 10 × 1:00 @ 3–4 10 × 0:45 @ 4–5	32.5
Tuesday	7:00 @ RPE 3 6:00 @ RPE 3 5:00 @ RPE 3 4:00 @ RPE 3 3:00 @ RPE 4 2:00 @ RPE 4 4 × 1:00 @ RPE 4–5	31	6:00 @ RPE 3 5:00 @ RPE 3 4:00 @ RPE 3 3:00 @ RPE 4 2:00 @ RPE 4 6 × 1:00 @ RPE 5	26
Wednesday	45:00 @ RPE 2–3	45	45:00 @ RPE 2–3	45
Thursday	3 × 3:00 @ RPE 2–3 3 × 1:00 @ RPE 4–5 repeat × 3	36	4 × 3:00 @ RPE 2–3 6 × 1:30 @ RPE 3–4 8 × 0:45 @ RPE 4–5 2 × 3:00 @ 3–4	33
Friday	8:00 @ RPE 2 7:00 @ RPE 3 6:00 @ RPE 3 5:00 @ RPE 3 4:00 @ RPE 3 3:00 @ RPE 3–4 2 × 1:00 @ RPE 4–5	35	4 × 2:00 @ RPE 2–3 6 × 1:30 @ RPE 3–4 8 × 1:00 @ RPE 4–5	25
Saturday	10 × 1:00 @ RPE 3–4 10 × 0:45 @ RPE 4 10 × 0:30 @ RPE 4–5	22.5	5:00 @ RPE 2–3 4:00 @ RPE 3–4 3:00 @ RPE 3–4 2:00 @ RPE 4–5 1:30 @ RPE 4–5 1:00 @ RPE 4–5 Repeat × 2	33
Sunday	45:00 @ RPE 2–3	45	45:00 @ RPE 2–3	45

All workouts also included a 5-min warm-up and a 5-min cool-down.
Workouts are written in the following form: number of repetitions × duration of repetition (min:s) @ exertion level (1–5 scale).

(WET VEST, Birmingham, AL) during all DWR training. Swimming pool temperature was 26–27° C. The training regimen involved 5–6 $d \cdot wk^{-1}$ of DWR training for a total of 20–24 sessions (mean ± SD; 22 ± 1.5 sessions). All training sessions were monitored by an investigator. Standardized water workouts (6) consisting of long and short interval (2 d each) as well as long duration (1 or 2 d) sessions were used (see Table 1). While the training volume and duration were similar to that of the subjects'- normal training, we did not attempt to precisely match the previous OLR with DWR training. Instead, we used a standard protocol recommended for DWR (6) to simulate a protocol typically used by a runner with an injury. The Brennan Scale (24), a 5-point perceived exertion scale, was used to set the workout intensity. The scale has verbal descriptors ranging from very light to very hard. Each level is also equated with OLR intensities as follows: level 1 corresponds to a light jog or recovery run, level 2 corresponds with a long steady run, level 3 corresponds to a 5- to 10-km race, level 4 corresponds to a 400- to 800-m track interval, and level 5 corresponds to sprinting 100–200 m (24). Michaud et al. (16) also used this scale to prescribe intensity for DWR exercise in healthy sedentary individuals.

Both pre- and post-training, the runners completed a combined lactate threshold (LT) and maximal oxygen consumption ($\dot{V}O_{2max}$) test on one day and a running economy test and a simulated 5-km race on the treadmill on another day. The pre-training tests were conducted at least 4 d apart with the subjects continuing to OLR between the two test days. The post-training tests were conducted at least 2 d apart with the subjects continuing with DWR training or not training between testing days. Subjects were instructed to perform a light or no workout the day before all tests to allow for maximal effort in testing.

The LT/$\dot{V}O_{2max}$ test was a modification of the protocol used by Tanaka et al. (21). The initial pace was set at 53.6 $m \cdot min^{-1}$ slower than the subject's average self-reported 10-km race pace. The speed was progressively increased by 20.1 $m \cdot min^{-1}$ every 3 min until volitional fatigue. Exercise was interrupted for approximately 1 min for blood sampling at the end of each 3-min work bout. Expired gases were sampled continuously from a mixing chamber. Oxygen and carbon dioxide were analyzed using Applied Electrochemistry SA-3 (Applied Electrochemistry Inc., Sunnyvale, CA) and Applied Electrochemistry CD-3A (Ametek, Thermonax Instruments Division, Pittsburgh, PA) analyzers, respectively. Inspired volume was measured using a Rayfield Air Flow Meter (Rayfield Equipment Ltd., Waitsfield, VT). Heart rate was monitored during the pre-training $\dot{V}O_{2max}$/LT test via a 12-lead electrocardiogram (Quinton, Seattle, WA) and during the post-training test via radiotelemetry (Polar Favor, Polar Electro Inc., Port Washington, NY).

Approximately 100 μL of capillary blood was obtained from a fingertip for blood lactate analysis. All samples were analyzed using the YSI 23-L lactate analyzer (Yellow Springs Instruments, Yellow Springs, OH). LT was defined as the point after which blood lactate began to increase nonlinearly during the incremental work test. As in the study by Hughes et al. (12), LT was determined for each subject from a plot of blood lactate versus work rate. Inflection points in the individual curves were identified by three different evaluators who were blind to the order of testing. Each was given specific instructions and was provided with an example of the data prior to their rating. The LT value for a given trial was determined by averaging the two closest values. The correlation between the two closest values was high (r = 1.00 for pre-training, r = 1.00 for post-training LT).

$\dot{V}O_{2max}$ was considered to be the average of the two highest $\dot{V}O_2$ values in the series of 30-s $\dot{V}O_2$ values (21). Criteria used for documentation of $\dot{V}O_{2max}$ included the following: plateau in $\dot{V}O_2$ (increase of less than 150 $mL\cdot min^{-1}$) (15), a peak lactate value greater than 8 $mmol\cdot L^{-1}$ during recovery (21), an R value of 1.1 or greater (15), and heart rate within 10 beats of predicted maximum (15). Each subject met at least two of these criteria.

Running economy, or the oxygen consumption ($mL\cdot kg^{-1}\cdot min^{-1}$) required to run at a fixed velocity, was assessed prior to the 5-km time trial. The subject ran for 7.5 min on the treadmill at a fixed velocity that corresponded to 70% pre-training $\dot{V}O_{2max}$. To assess the steady state $\dot{V}O_2$, expired gases were collected in Douglas bags and were analyzed for oxygen and carbon dioxide using the previously described analyzers. Expired volume was measured using a Tissot spirometer (Warren E. Collins, Inc., Braintree, MA). During the final 2 min of the running economy test the subject's heart rate and rating of perceived exertion (RPE, Borg scale 6–20) (4) were also recorded.

Subjects were allowed to recover between the running economy test and the 5-km treadmill time trial. This was not a controlled period of time but was similar between trials. In most cases the 7.5-min submax run was used as a warm-up and the subjected completed the 5-km time trial shortly after the running economy test. In some cases, the subjects requested and were allowed an additional warm up prior to the 5 km. Whichever scenario was selected for the pre-training testing was duplicated for the post-training tests.

The 5-km "time trial" was run on a treadmill equipped with front and rear photocells (Thyrotronics CP-122, Los Angeles, CA). When the runner's body blocked the front beam, treadmill velocity increased and when the runner's body blocked the back beam, treadmill velocity decreased. A third photocell was directed toward a segment of retroflective tape mounted on the treadmill belt, and each revolution tripped a relay which signaled the input/output board (John Bell 87–016A, Los Angeles, CA) mounted in an IBM (Armonk, NY) personal computer. A compiled BASIC computer program counted and timed each revolution of the treadmill belt and computed speed and distance covered throughout the run. Constant visual feedback was given to the subject on the speed (miles per hour and minutes per mile) and distance covered via video display. The test-retest reliability of this system was strong (r = 0.99) as was the correlation between the computer 5-km race and a 5-km road race (r = 0.98) (unpublished observation). RPE was also obtained at 1.6 and 3.2 km during the race to assess the runner's perception of effort. All subjects ran on the treadmill twice prior to the pre-training 5-km run to become familiar with the computerized system.

Mood state was assessed using the Profile of Mood States (POMS). The POMS was administered to examine whether the subjects would experience a negative shift in mood when their normal OLR was replaced with DWR. The questionnaire was completed prior to the training period, each week during the DWR training, and the week following the training period. Subjects were asked to indicate how they had been feeling during the previous week, including the day the questionnaire was completed. Global mood state was calculated by adding the scores from tension, depression, anger, fatigue, and confusion scales, subtracting the vigor score, and adding a constant of 100 to avoid negative numbers (17).

STATISTICAL DATA ANALYSIS

Paired *t*-tests were used to compare the pre- and post-training dependent variables ($\dot{V}O_{2max}$, maximal lactate, maximal heart rate during the $\dot{V}O_2$/LT tests; $\dot{V}O_2$, heart rate, and RPE during the running economy tests; race time and 3.2 km RPE during the 5-km race). To compare the 1.6 km RPE during the 5-km race and also to compare the lactate threshold during the $\dot{V}O_2$/LT test, both of which failed the normality test, the Wilcoxon signed rank test was used. To control for type I error, the Bonferroni method was used where the selected alpha level of 0.05 was divided by the number of *t*-tests performed ($N = 10$). Thus for all *t*-tests an alpha level of $P < 0.005$ was used. One-way ANOVA with repeated measures were used to assess the effect of the training period on the individual POMS variables (alpha level of $P < 0.05$).

RESULTS

No significant differences were found pre- to post-training for $\dot{V}O_{2max}$, maximal heart rate, maximal lactate, or LT running velocity (Table 2). No significant differences were found between the pre- and post-training submaximal runs for $\dot{V}O_2$, i.e., running economy was not significantly changed after 4 wk of DWR training. In addition, no significant differences were found for HR or

TABLE 2. Effects of 4 wk of deep water run training on lactate threshold running velocity and maximal exercise responses.

Parameter	Pre ($N = 11$)	Post ($N = 11$)
Lactate threshold Running velocity ($m \cdot min^{-1}$)	249.1 ± 9.9	253.6 ± 6.3
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	63.4 ± 1.3	62.2 ± 1.3
Maximal blood lactate ($mmol \cdot L^{-1}$)	9.3 ± 0.6	8.3 ± 0.5
HR_{max} ($beats \cdot min^{-1}$)	196.3 ± 2.9	191.2 ± 3.3

Values are means ± SEM.

TABLE 3. Effects of 4 wk of deep water run training on submaximal exercise responses.

Parameter	Pre ($N = 11$)	Post ($N = 11$)
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.8 ± 1.2	45.3 ± 1.5
HR ($beats \cdot min^{-1}$)	158.2 ± 5.0	158.4 ± 4.4
RPE (6–20 scale)	11.2 ± 0.2	11.2 ± 0.3

Values are means ± SEM., submaximal exercise was equivalent to a 7.5-min treadmill run at 70% pre-experimental $\dot{V}O_{2max}$.

TABLE 4. Effects of 4 wk of deep water run training on 5-km treadmill time trial and rating of perceived exertion at 1.6 and 3.2 km.

Parameter	Pre ($N = 10$)	Post ($N = 10$)
5-km treadmill time trial (s)	1142.7 ± 39.5	1149.8 ± 36.9
1.6-km RPE (6–20 scale)	14.5 ± 0.7	14.4 ± 0.8
3.2-km RPE (6–20 scale)	16.4 ± 0.6	16.0 ± 0.7

Values are means ± SEM.

RPE between the pre- and post-training submaximal runs (Table 3). No significant differences were found between the pre- and post-training 5-km time trials or for RPE at either 1.6 km or 3.2 km (Table 4). Global mood state was not different among the time points (pre-training, 111.3 ± 6.9; week 1, 104.2 ± 5.3; week 2, 104.9 ± 6.7; week 3, 98.7 ± 6.3; week 4, 103.2 ± 9.6, post-training 101.4 ± 6.0, means ± SEM), nor were any of the subscores significantly different.

Statistical power was calculated for all dependent variables. Statistical power for running economy and POMS was 0.05, for $\dot{V}O_{2max}$ was 0.24, HR_{max} was 0.28, Lmax was 0.50, for 5-km run time was 0.08. Although we believe that the experimental design was sound, given the overall negative findings of the study, the experiment may not have provided adequate power to test the null hypotheses. Low statistical power is potentially associated with Type II statistical error. To examine the possibility that failure to reject the null hypotheses was simply a result of a small sample size, power analyses were conducted. For example, based on an SD of 117 and alpha of 0.05, even a sample of 2000 subjects would not have resulted in a significant difference between pre- and post-training 5-km time trials. Thus, the failure to find statistically significant differences was likely not a result of small sample size but rather a result of no real differences pre- to post-training.

DISCUSSION

Four weeks of DWR training apparently provided a sufficient training stimulus to maintain OLR performance in a group of well-trained distance runners. Maintenance of running performance with DWR training is consistent with the findings of Eyestone et al. (8) who found that recreationally active subjects were able to maintain 1.6-km run time (on an indoor track) after 6 wk of DWR. In that study, however, the subjects were not experienced runners, and the authors acknowledged that a learning effect may have confounded their findings, i.e., the subjects learned from the initial run how to better pace themselves during the post-training run. In contrast, subjects in this study were experienced road racers and were allowed two practice sessions on the treadmill. The 5-km treadmill time trials used in this study allowed for simulation of a maximal performance; however, other variables have the potential to affect a person's ability to compete in a true race situation. Further data following such a performance would be useful in future studies.

No significant differences were found pre- to post-training for the other performance measures: running economy, $\dot{V}O_{2max}$, lactate threshold. These findings are supported by Wilber et al. (23) who examined the effect of a 6-wk DWR or OLR training program on maintenance of running performance (as defined by running economy, $\dot{V}O_{2max}$, and lactate threshold). Their subjects were well-trained ($\dot{V}O_{2max}$ 58.6 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$) as were the subjects in the present study (62.8 ± 4.2 $mL \cdot kg^{-1} \cdot min^{-1}$). Wilber et al. found no significant differences for running economy, $\dot{V}O_{2max}$, or lactate threshold between a group of DWR trained and a group of treadmill trained subjects (23). The present study is unique in that it was the first to examine the effects of DWR on OLR performance times in competitive runners.

Quinn et al. (18) used a 4-wk DWR training period, as in the present study, but found the stimulus was insufficient to maintain $\dot{V}O_{2max}$. The subjects were trained for 10 wk with OLR followed by the 4 wk of DWR. Potential limitations acknowledged by the authors were the steady-state DWR training protocol and the workout intensity (80% of heart rate reserve minus 10 $beats \cdot min^{-1}$). The authors suggested the potential importance of interval, tempo, and fartlek training on a weekly basis to maintain functional capacity. They also noted the possibility that the prescribed exercise intensity was not sufficient to maintain $\dot{V}O_{2max}$. In a study by Eyestone et al. (8), subjects were also unable to maintain $\dot{V}O_{2max}$ over a 6-wk DWR training period. The decline in $\dot{V}O_{2max}$ may have been a result of insufficient training stimuli. For the first week, their subjects trained at the minimum frequency (3 $d \cdot wk^{-1}$), duration (20 $min \cdot d^{-1}$), and intensity (70% heart rate max) for developing and maintaining cardiorespiratory fitness as recommended by the American College of Sports Medicine (1). During weeks 3 to 6 the subjects trained 5 $d \cdot wk^{-1}$, 30 $min \cdot d^{-1}$ at 80% heart rate max. Since improvement in $\dot{V}O_{2max}$ is directly related to frequency, intensity, and duration of exercise (1), it may be that when the subjects were training at the minimum ACSM-recommended levels that the training stimulus was insufficient. In contrast, Michaud et al. (16) found that an 8-wk progressive, aerobic, interval DWR program produced an improvement in $\dot{V}O_{2max}$ of 10.6% in healthy sedentary individuals (16). Their interval workouts, similar to those used in the present study, involved exercise and rest periods with the total exercise time between 16–36 min, depending on the protocol for that day.

Hickson et al. (10) found that $\dot{V}O_{2max}$ was not maintained over a 15-wk period of reduced training intensity (33% or 67% reduction) following a 10-wk training period in a recreationally active group. At 5 wk into the detraining period, the subjects whose training was reduced by 67% had significantly lower $\dot{V}O_{2max}$ than when they were trained. In contrast, McConell et al. (14) found that $\dot{V}O_{2max}$ was maintained after 4 wk at reduced training volume (−66%), frequency (−50%), and intensity (less than 70% $\dot{V}O_{2max}$) in well-trained distance runners. McConell et al. (14) also evaluated 5-km running performance and found that completion time was significantly increased after the reduced training period. They suggested that the reduction in training volume and intensity allowed for maintenance of aerobic capacity but that reduced intensity was important for maintenance of 5-km running performance. The subjects in the present study maintained $\dot{V}O_{2max}$ as well as 5-km running performance and were therefore apparently training at a sufficient intensity.

Our subjects trained an average of 5 $d \cdot wk^{-1}$ (mean ± SD for 4 wk: 22 ± 1.50 sessions). According to the American College of Sports Medicine position statement: "the value of the added improvement found with training more than 5 $d \cdot wk^{-1}$ is small to not apparent in regard to improvement in $\dot{V}O_{2max}$" (1). Therefore, training 5 $d \cdot wk^{-1}$ would be expected to have provided the necessary stimulus to maintain $\dot{V}O_{2max}$ assuming the duration and intensity were sufficient. In the month preceding the DWR, subjects trained 4.3 ± 1.3 d and 43.2 ± 15.4 $km \cdot wk^{-1}$ (mean ± SD). Hickson and Rosenkoetter (11) found that $\dot{V}O_{2max}$ was maintained after up to 15 wk of reduced frequency of training (from 6 $d \cdot wk^{-1}$ for 10 wk to 2–4 $d \cdot wk^{-1}$ for 15 wk). Our subjects did not reduce the frequency of training and thus were able to maintain $\dot{V}O_{2max}$.

The POMS was administered to examine whether the subjects would experience a negative shift in mood when their normal OLR was replaced with DWR. A negative shift in mood was not evident in these runners. Wittig et al. (26) investigated the effect of reduced training volume (70% reduction) for 3 wk on performance (5-km) and mood state (POMS). They found that 5-km race time was not affected and that there was actually an improvement in global mood state following the 3 wk of reduced training volume. In a subsequent study, Wittig et al. (27) investigated the effect of a 4-wk reduction in training volume (66% reduction) and intensity (all workouts were below 70% $\dot{V}O_{2max}$) on running performance (5-km) and mood state (POMS). They found that the runners required more time to complete a 5-km time trial and also had an increased total mood disturbance. They attribute the discrepancy in their findings to the influence of intensity. Therefore, the intensity of the DWR appears to have been high enough to maintain both the 5-km time as well as the subjects' mood state. The possibility also exists that increased social interactions with the researchers and other subjects during the study had a positive influence on mood state (13), thus negating any negative shift resulting from a change in training.

The purpose of this study was to determine whether 4 wk of DWR training would be a sufficient training stimulus to maintain OLR performance. Based on the results, we conclude that DWR provided a sufficient stimulus. A group of well-trained distance runners maintained 5-km treadmill race performance using 4 wk of DWR. In addition, maximal oxygen consumption, maximal heart rate, maximal lactate, lactate threshold, running economy, submaximal rating of perceived exertion and perceived exertion during the 5-km race were not different. Lastly, 4 wk of DWR did not affect global mood state. Future studies should examine the effects in elite distance runners to determine if the same conclusions can be drawn with athletes of that level of fitness. Also, in future studies the training period should be extended with serial testing during the training period.

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