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Changes in peak leg power induced by successive judo bouts and their relationship to lactate production

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Abstract

Eleven male judoka, who compete at national level, were recruited with the aim of investigating changes in peak leg power as a result of successive judo bouts and their relationship with lactate production. The participants executed a force–velocity curve to determine peak power in a 90° squat exercise in concentric work. The group then participated in four 5-min judo bouts each separated by 15 min of passive rest. The power developed as a result of the load associated with the maximum peak power reached in the preliminary test was determined, for the same movement, before and after each bout. Finger capillary blood samples were taken after each bout to determine the maximum lactate concentration achieved and lactate clearance. The results showed no effect of successive bouts on peak leg power ($P > 0.05$) and no difference when comparing the power measured before and after each bout ($P > 0.05$). Maximum lactate concentration of the fourth bout was lower than that of the first (12.6 ± 3.5 and 14.6 ± 4 mmol $\cdot$ l^{-1} respectively; $P < 0.05$), although there was no difference in their clearance dynamics ($P > 0.05$). On the basis of the results obtained, we conclude that successive judo bouts, with the structure proposed in this study, produce high acidosis levels, which have no effect on the peak power developed in the legs.

Keywords: *Judo, peak power, legs, lactic acid*

Introduction

The relationship between metabolic processes and strength demanded in fight sports such as judo has been analysed in several studies (Bonitch-Góngora, 2007; Carballeira, Iglesias, & Calvo, 2008; Muramatsu et al., 1994). One of the fundamental characteristics of a judo bout is its intermittent nature (Artioli et al., 2005; Franchini, Takito, Nakamura, Matsushigue, & Peduti Dal'molin, 2003), with highly intense periods of effort (with a mean duration of between 15 and 30 s) alternating with rest periods of around 10–15 s (Castarlenas & Planas, 1997; Gorostiaga, 1988; Sikorski, Mickiewicz, Majle, & Laksa, 1987). There is insufficient time during these periods of rest to resynthesize creatine phosphate, which means that the role of lactic anaerobic metabolism is important at the beginning of a bout and this is progressively complemented with a contribution from aerobic metabolism as the combat and competition advance (Muramatsu et al., 1994; Tabata et al., 1997). The contribution of anaerobic metabolism is clearly indicated by the high blood lactate concentrations shown by judoka after bouts (between 13 and 18 mmol $\cdot$ l^{-1}) (Franchini et al., 2003; Gorostiaga, 1988; Sbriccoli, Bazzucchi, Di Mario, Marzattinocci, & Felici, 2007; Tumilty, Hahn, & Telford, 1986). Furthermore, judoka frequently participate in several bouts throughout the day, normally separated by a minimum recovery period of 15 min (Franchini et al., 2003). According to Sahlin (1992), the mean return times from maximum lactate to basal values range between 30 and 60 min. For this reason, it is possible that the judoka's lactate clearing capacity and/or the time between one bout and the next affects subsequent performance.

The link between increased blood lactate concentration and a drop in intracellular pH has been well documented (Dawson, Gadian, & Wilkie, 1978; Gladden, 2004), together with the inhibition of muscular function and a reduction in power and strength (Metzger & Moss, 1990; Szygula, Gawronski, & Kalinski, 2003). Nevertheless, the effect that the elevated lactate/H$^+$ concentration exerts on muscle contractile activity has at times been

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questioned (Bangsbo, Johansen, Quistorff, & Saltin, 1993; Brooks, 2001; Westerblad, Allen, & Lännergren, 2002), even though many of these studies were not performed under physiological temperature conditions (Westerblad et al., 2002). Other studies consider this action to be indirect, because of the effect that extracellular acidosis can exert on the muscles' pain receptors, contributing to the sensation of discomfort and increasing the release of potassium from the muscle cells (Szygula et al., 2003; Westerblad et al., 2002). Thus, Abdessemed and colleagues (Abdessemed, Duche, Hautier, Poumarat, & Bedu, 1999) have suggested that this loss of muscle power is the result of a build-up of H^+ when the rest period is not sufficient for its total clearance or for full resynthesis of aerobic adenosine triphosphate and creatine phosphate reserves, increasing the concentration of inorganic phosphate (Westerblad et al., 2002).

Force and power are considered to be essential requisites for achieving a high level of performance in judo (Fagerlund & Hakkinen, 1991; Little, 1991; Sbriccoli et al., 2007; Thomas, Cox, Legal, Verde, & Smith, 1989). Fagerlund and Hakkinen (1991), for example, have concluded that leg force and power can be used to discriminate between judoka of different competitive standards. In light of this, several studies have assessed the power of judoka from a metabolic perspective using the Wingate test (Franchini et al., 2003; Little, 1991; Sbriccoli et al, 2007; Thomas et al., 1989), whereas others have assessed the power from a more mechanical point of view by determining the height achieved in a jump test (squat jump, countermovement jump) (Filaire, Maso, Degoutte, Jouanel, & Lac, 2001; Iglesias, Clavel, Dopico, & Tuimil, 2003; Monteiro, García, & Carratalá, 2007). The incorporation of dynamic electronic dynamometers into the field of sports training has opened up the possibility of assessing the power directly (W) by calculating the product of the force applied (N) and the displacement velocity ($m \cdot s^{-1}$) in certain sporting actions. However, very few studies have analysed the actions of judoka using this methodology (Bonitch-Góngora, 2007; Monteiro et al., 2007), particularly combat-related movements.

An understanding of the role played by leg power during a judo bout is important, as actions have to be performed at high speed under the effects of an overload consisting of the judoka's own weight and that of his or her opponent (Iglesias, Fernández del Olmo, Dopico, Carratalá, & Pablos, 2000). Furthermore, this type of effort is repeated constantly during the bout in increasingly unfavourable metabolic conditions. The interaction between metabolic fatigue and power in successive judo bouts has been analysed for the arm-push action (Bonitch-Góngora, 2007) and jump height for the legs (Carballeira et al., 2008; Iglesias et al., 2003), although no studies on the effect on the leg-push power have been published.

In light of the above, the main aim of this study was to assess the behaviour of leg power during a simulated judo competition and its interaction with metabolic force-induced changes.

Methods

Participants

The study sample consisted of 11 male judoka, nine of whom were currently, or had been, medallists in national championships in Spain and France and had participated in several international tournaments; the remaining two had won medals in regional competitions in Andalusia (Spain). All participants had at least 8 years' experience and trained for between 10 and 12 h a week. Their technical levels ranged from 1st to 2nd Dan. They were grouped by weight and competitive level. The biometric characteristics of the sample are listed in Table I.

The evaluation protocol received approval from the Research Committee of the University of Granada's Department of Physical Education (local ethics committee), and written informed consent was obtained from all participants.

Study design

Each judoka participated in a simulated judo contest consisting of four bouts separated by a set passive recovery period. Leg power before and after each bout was determined using the load for each participant's maximum power calculated during a preliminary test. Blood samples were taken during the recovery period to determine the maximal lactate concentration and lactate clearance between bouts.

The participants were informed of the need to complete all four bouts. In the event of ippon, the losing judoka was instructed to get to his feet quickly and continue until the end of that bout.

Preliminary test

All participants undertook a preliminary test 48–72 h before the experimental protocol. This test consisted of performing a maximal incremental test, in a squat

Table I. Characteristics of the study population ($n = 11$).

Variable	mean $\pm$ s
Age (years)	22.7 $\pm$ 3.0
Weight (kg)	79.2 $\pm$ 17.6
Height (m)	1.79 $\pm$ 0.05
Percent body fat	12.1 $\pm$ 3.3

action with concentric work only, to determine the force–velocity curve. During squat tests, the participants' shoulders were in contact with a bar positioned so that the knee starting angle was 90° (measured manually by goniometer). On command, the participant performed a concentric leg extension as fast and as forcefully as possible, starting from the flexed position to reach the full extension of 180° against the resistance determined by the weight plates added to both ends of the bar, whereas the trunk was kept as straight as possible (Requena et al., 2009).

After a normal warm-up, the test began with a load of 20 kg (barbell load), which was increased by 5, 10 or 20 kg per series. The last acceptable extension with the highest possible load was defined as the maximum load displaced. Two repetitions were performed per series until the bar displacement velocity fell below 0.3 m $\cdot$ s^{-1}, whereupon only one repetition was performed. The rest period between series was 3 or 5 min for velocities above or below 1 m $\cdot$ s^{-1}, respectively. The load discs used were calibrated beforehand with a suspended tensiometric cell; loads that did not deviate by more than 0.5% from their expected weight were considered valid. All participants were strongly encouraged to ensure that the velocity of each repetition was maximal.

The power of each repetition was determined by incorporating a dynamic Isocontrol system (JLML I+D, 1996), running I.D. software (version 3.6, 2002) (Requena et al., 2009), into the bar. The system was mounted with a 200-cm encoder and 2 N of isocontrol resistance in the vertical plane of the bar's displacement. The data provided by the software showed the peak power, velocity, and force generated in each repetition. The highest value recorded by the system during the increasing load tests was taken to be the maximum peak power. The participants showed a good coefficient of variation (CV%) of peak power between test–retest trials (7.7%).

Experimental protocol

The experimental protocol involved each jukoda participating in a simulated judo contest. This protocol reproduces the real judo combat activity and physiological responses (e.g. temporal structure and blood lactate concentration) as described in the literature (Franchini el al., 2003; Sbriccoli el al., 2007). The contest consisted of four 5-min judo bouts (actual combat time), each separated by 15 min of passive recovery (Degoutte, Jouanel, & Filaire, 2003; Franchini et al., 2003; Franchini, Cássio de Moraes Bertuzzi, Takito, & Kiss, 2009). Each bout took place on a regulation tatami judo mat installed in the School of Exercise and Sports Science of the University of Granada, and was controlled by referees and timekeepers from the Andalusian Judo Federation and Associated Disciplines. To ensure that all bouts lasted for the officially allotted time, the official regulation which specifies "a contest will end when one contestant has achieved ippon or equivalent" (article 19 of the International Judo Federation's Referee Rules) was modified so that victory in our study was decided at the end of the bout by totalling all the points scored (yuko = 5 points; waza-ari = 7 points; ippon = 10 points; and the sum of shido, with its equivalence to yuko, waza-ari or ippon). All contests took place between 10:00 and 14:00 h, and the temperature of the room varied between 16 and 20°C.

To generate a demanding competitive environment, the participants were divided into pairs of the same weight (difference of less than 10%) and similar ranking (Franchini et al., 2003) (rankings published by the Andalusian Federation of Judo and Associated Disciplines) and were paid for each victory achieved.

The supports for the bars and platforms, with connections to the dynamic Isocontrol system, were set up, in duplicate, at a distance of 4 m from the judo mat's safety zone, in the same conditions used during the preliminary test. In the 30 s before and after each bout, the judoka reproduced the 90° squat movement with the load displaced at the peak power of the corresponding preliminary test. A single repetition was performed to obtain the power before and after each of the bouts.

A 10-μl sample of capillary blood was taken from the fingertip 1, 3, 5, and 14 min after each bout and lactate concentration was determined using a photo-enzymatic system (Dr. Lange, LP 20 plus) (Feriche et al., 2007). The highest lactate concentration reached between bouts was taken as the maximum value (maximal blood lactate concentration). The percentage of lactate clearance between bouts was determined from the difference between maximal blood lactate concentration and the lactate concentration at minute 14 of the recovery period.

To ensure that the temporal structure of the contests was as close as possible to the competition conditions, the entire experimental phase was recorded with a Sony DCR-TRV14OE digital camera. The mean effort and rest periods, and the number of attacks were calculated for each bout. The reliability of this method has been established previously (Castarlenas & Planas, 1997; Degoutte et al., 2003; Gorostiaga, 1988).

Statistical analysis

All data are expressed as means ± standard deviations (*s*). The frequency distribution was obtained from the Shapiro-Wilk test. The difference between the variables before and after each bout was determined using a repeated-measures analysis of variance (ANOVA) with two intra-participant factors [Factor 1: bouts (1, 2, 3 and 4); Factor 2: time of measurement (before and after)]. The intra-participant effect was determined using the Greenhouse-Geisser test or the Huynh-Feldt correction for degrees of freedom if the result of the Mauchly sphericity test was significant. For subsequent multiple comparisons, Sidak's Modified Test was performed in the case of a significant ANOVA. A Pearson or Spearman correlation analysis was used to analyse the inter-variable relationships. A 95% confidence interval was established.

Results

The mean time for the rest and effort phases during the bouts was 13.7 ± 9.6 and 10.8 ± 7.1 s respectively, and the mean number of attacks during each bout was 10.8 ± 3.6.

The results obtained in the preliminary tests are shown in Table II. The relative peak power developed during this test was 25.4 ± 3.3 W · kg^{-1}. There was no significant difference between peak power for the preliminary test and power before bout 1 ($P > 0.05$).

The power, force, and velocity before and after each bout are shown in Table III. There was no overall effect of the successive bouts on the time of measurement (before or after) or the bout–time interaction on these variables ($P > 0.05$).

Results for blood lactate concentration during the recovery periods are shown in Table IV. The effect of successive bouts on maximal blood lactate concentration was significant ($P < 0.05$). The pair-comparison analysis showed a significant drop in blood lactate concentration for the fourth bout with respect to the first bout (12.6 ± 3.5 and 14.6 ± 4.0 mmol · l^{-1}, respectively; $P < 0.05$). There was no change between the blood lactate concentration at minute 14 and percentage of lactate clearance values between bouts ($P > 0.05$).

Table II. Peak-power and associated loads and peak dynamic force in the study population ($n = 11$).

Variable	mean $\pm$ *s*
1-MR (kg)	186.4 ± 36.7
Load at peak power (kg)	130.9 ± 31.8
%1-MR at peak power	70.3 ± 9.9
Peak power (W · kg^{-1})	25.4 ± 3.3
Peak power (W)	1993.7 ± 370.0
Force (N)	1771.2 ± 416.5
Velocity (m · s^{-1})	1.12 ± 0.06

Note: 1-MR = maximum load displaced; %1-MR at peak power = load displaced at peak power.

Table III. The effect of successive bouts on the power, force, and velocity before and after each bout.

	Bouts								
	1		2		3		4		
	before	*after*	*before*	*after*	*before*	*after*	*before*	*after*	*P*-value
Peak power (W · kg^{-1})	25.0 ± 3.5	25.3 ± 3.6	25.4 ± 2.7	23.3 ± 4.7	24.5 ± 3.5	24.6 ± 3.7	24.6 ± 3.1	25.5 ± 3.9	$P > 0.05^{a,b,c}$
Peak power (W)	1969.7 ± 439.2	1976.6 ± 366.1	1993.8 ± 342.4	1821.2 ± 453.4	1917.9 ± 345.9	1919.8 ± 357.6	1917.8 ± 275.9	2013.0 ± 453.9	$P > 0.05^{a,b,c}$
Force (N)	1739.4 ± 404.4	1756.8 ± 370.7	1762.2 ± 402.3	1699.9 ± 357.4	1733.8 ± 370.6	1751.7 ± 387.1	1731.7 ± 349.0	1773.1 ± 398.8	$P > 0.05^{a,b,c}$
Velocity (m · s^{-1})	1.14 ± 0.11	1.14 ± 0.13	1.15 ± 0.12	1.07 ± 0.16	1.12 ± 0.13	1.12 ± 0.15	1.12 ± 0.13	1.14 ± 0.14	$P > 0.05^{a,b,c}$

[a]Combat main effect (bout number 1 to 4). [b]Time of measurement main effect (before/after). [c]Interaction between time (before/after) and bout.

Table IV. The effect of successive bouts on lactate clearance between bouts (mean ± s).

Variable	Bout 1	Bout 2	Bout 3	Bout 4	P-value
Maximal blood lactate concentration ($mmol \cdot l^{-1}$)	14.6 ± 4.0	14.9 ± 4.0	13.9 ± 2.8	12.6 ± 3.5	$P < 0.05$
Blood lactate concentration at minute 14 ($mmol \cdot l^{-1}$)	9.2 ± 3.1	8.7 ± 3.2	8.1 ± 2.4	7.5 ± 2.5	$P > 0.05$
% lactate clearance	37.2 ± 11.3	41.9 ± 9.2	42.5 ± 6.7	40.9 ± 7.7	$P > 0.05$

Table V. Correlation between maximum lactate concentration and leg power before and after its determination.

		Bout 1		Bout 2		Bout 3		Bout 4	
	Bout	*PB*	*PA*	*PB*	*PA*	*PB*	*PA*	*PB*	*PA*
Maximal blood lactate concentration ($mmol \cdot l^{-1}$)	1	−0.13	−0.53	−0.27					
	2			−0.48	0.03	−0.44			
	3					−0.38	−0.31	−0.36	
	4							−0.35	−0.46

PB = power before bout; *PA* = power after the bout.

The results of the correlational analysis between power and maximum lactate concentration are shown in Table V. There was no relationship between the pairs studied ($P > 0.05$).

Discussion

Force actions performed under adverse metabolic conditions during judo bouts have made analysis of the interaction or association between neuromuscular and metabolic factors increasingly important. The main finding of this study is the lack of significant changes in peak leg power during the 90° squat with concentric force movement as a result of four successive judo bouts. In all cases, the maximum lactate concentrations reached show the intense efforts made by the judoka, although, in contrast to what was expected, this appears not to affect their ability to perform the action studied. The metabolic recovery between bouts (15 min of passive recovery) is incomplete, although this also appears to have little or no effect on the mechanical ability of the legs to achieve an optimal force–velocity ratio during the extension.

Analysis of the demands and effects of a judo contest on the power of the classical push action are relatively uncommon in the scientific literature, although it is thought that a high power value for the legs is essential to meet the functional demands imposed by this discipline (Sbriccoli et al., 2007; Thomas et al., 1989). Fagerlund and Hakkinen (1991) have even reported that higher power and force levels in the legs are what distinguish top-class judoka from those of a lower competitive standard. The peak powers obtained by our study group (1981.7 ± 374.1 W and 25.0 ± 3.5 $W \cdot kg^{-1}$) are high and in agreement with the sample studied, as is the load displaced at peak power (70.3 ± 9.9% of one-repetition maximum). In general, these results are slightly higher than those shown in previous studies performed with athletes from different sports (Izquierdo, Häkkinen, González-Badillo, Ibáñez, & Gorostiaga, 2002). Likewise, the one-repetition maximum values obtained (186.4 ± 36.7 kg) are also in agreement with the sample's population profile and competitive standard (Baker, Nance, & Moore, 2001).

The direct determination of power is not a commonly used procedure in the evaluation of judoka force. Most of the studies reviewed use the height achieved in a jump test (squat jump, countermovement jump) as an indicator of power (Filaire et al., 2001; Iglesias et al., 2003; Monteiro et al., 2007). Because the movement patterns between the half-squats and the jumps are similar, a stronger relationship between the squat and jump might be expected. However, the two procedures evaluate different components of neuromuscular force and performance, which is why they should not be applied indiscriminately (Knudson, 2009), making comparison between published results and ours more difficult.

Each bout on its own, and the four successive bouts used in this study together, had no significant effect on the power that the legs could generate (see Table III; $P > 0.05$). This result is in accordance with the lack of significant change in force and velocity at power loads.

Similarly, other studies have not recorded changes in the height of a countermovement jump (Carballeira et al., 2008; Iglesias et al., 2003) and with arm movement (Iglesias et al., 2003) after one or two judo bouts, similar in structure to those used in the present study. Indeed, other studies show a different effect of combat on the upper body musculature. For example, Bonitch-Góngora (2007) recorded a significant decrease in grip force in both hands of 10–15%, which correlated positively with maximal blood lactate concentration, during four judo bouts in the same conditions used in this study. Nevertheless, the maximum arm power developed during a bench press action with overload was seen to increase at the expense of an increase in movement velocity, highlighting, as in our study, that it is independent of blood lactate concentration (Bonitch-Góngora, 2007). In line with this, Franchini et al. (2009), observed that the minimal recovery time reported in judo competitions (15 min) is long enough for the arms to recover sufficiently to maintain performance during a Wingate test. We propose that use of the arms during a bout is very intense whereas the legs perform power actions only occasionally, which is why performance of arm and leg musculature is presumed to be different and why different training intervention programmes should be used.

As stated in the Introduction, a judoka's actions during a bout are intermittent, with periods of intense force alternating with rest periods. This implies a variety of technical movements, each of which has a different energy demand, depending on the opponent and the judoka's degree of involvement (Franchini, Sterkowicz, Meira, Gomes, & Tani, 2008; Serrano, Salvador, González-Bono, Sanchís, & Suay, 2001). Our study group recorded 10.8 ± 3.6 attacks during the judo bouts, with each one lasting for 10.8 ± 7.1 s and being separated by a rest period of 13.7 ± 9.6 s. This work-to-rest dynamic appears to allow the mechanical power of the legs to be conserved (Linnamo, Häkkinen, & Komi, 1998), and highlights, as pointed out previously by Sbriccoli et al. (2007), the prevalence of a high degree of fatigue resistance characteristic of judoka.

When intermittent high-intensity forces are performed, aerobic metabolism is involved during both the work and recovery phases (Feriche et al., 2007). Furthermore, an increase in the aerobic contribution appears to partially compensate the decreased energy supply provided by anaerobic metabolism during this type of activity (Bogdanis, Nevill, & Lakomy, 1994; Wootton & Williams, 1983). Our results showed high lactate concentrations after the first assay (between 12 and 14 $mmol \cdot l^{-1}$), thereby highlighting the intensity of the bouts, in agreement with the values reported in other studies with a similar population and during competition (Ebine, Yoneda, & Hase, 1991; Franchini et al., 2003; Gorostiaga, 1988; Sbriccoli et al., 2007). In all cases, the accumulated lactate-clearance or -metabolization capacity remained unaltered, and the lactate concentrations before the second, third, and fourth bouts (blood lactate concentration at minute 14) were similar. We observed a decrease in the maximum lactate concentration after the bouts, with this drop being significant between the first and fourth bouts. However, the conservation of work capacity and power required during the tests before and after the bouts could suggest some form of compensation for the energy supplied, as suggested by other studies with forces of a similar strength (Gaitanos, Williams, Boobis, & Brooks, 1993; Tabata et al., 1997). We did not observe any relationship between the power values recorded and the maximum lactate concentrations between bouts (Table V). Carballeira et al. (2008) also found a lack of consistency in the causal relation between lactate concentration and maximum isometric force in leg muscles after a bout. The literature presents various mechanisms for why the increase in blood acidosis may reduce the quality of muscular contractions: blockage of glycolytic enzymes and its contribution to the retardation or interruption of glycolysis and adenosine triphosphate synthesis and increase in ammonia and inorganic phosphorus; limitation of calcium ion influx, irritation of muscle pain receptors causing compression of blood vessels and hampering access of working muscles to oxygen, or an increase in the accumulation of extracellular potassium making the action potential more difficult (Ahmaidi et al., 1996; Bangsbo, Madsen, Kiens, & Richter, 1996; Bogdanis et al., 1994; Degoutte et al., 2003; Hogan & Welch, 1984; Karlsson, Bonde-Petersen, Henriksson, & Knuttgen, 1975; Klausen, Knuttgen, & Foster, 1972; Weltman, Stamford, Moffat, & Katch, 1977; Yates, Gladden, & Cresanta, 1983). Nevertheless, H^+ formation is not exclusively from lactic acidosis. Inside the muscle fibre, H^+ ions are mostly buffered but some lactate along with H^+ is thought to be extruded via lactate-proton transporter proteins in the cell membrane (Juel, 1997). Our results, more in accordance with Bangsbo et al. (1996) and Cairns (2006), show that a blood lactate concentration of 12–14 $mmol \cdot l^{-1}$ does not affect the ability to maintain peak power, which means that the fatigue experienced during this type of selective recruitment action is a result of other factors (e.g. electrolytes) that recover more quickly than muscular pH, so that the interactive effects are lost.

Conclusions

The factors related to the metabolic processes involved and the manifestations of the force required have, in general, been considered separately. The aim of this study was to assess how these two factors are affected by the complex effort undertaken by the judoka and to determine the relationship between the metabolic needs, in terms of lactate concentration, and any possible effect on the judoka's leg power. Based on the results of our study, we conclude that a bout, or a succession of bouts, in a simulated judo contest results in a high demand on the lactic anaerobic metabolism, which does not, however, affect the capacity to generate high leg power in the movement employed in this study. The high peak power and fatigue resistance demonstrated by these competitors suggest that conditioning sessions should concentrate on developing the peak power at high loads and its resistance component. Also, lactic anaerobic metabolism should be stimulated during training using intermittent high-intensity forces in the work/rest regime that is established during a bout and is described herein.

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