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Accuracy of Horse-Riding Energy Consumption according to Accelerometer Wearing Location

Jungeun Park, Hanju Ahn, Seungyun Shin, & Mihyun Lee*
Yongin university

Abstract

The purpose of this study is to verify the accuracy of energy consumption per wearing location (waist, wrist, ankle) of uniaxial accelerometer (GT1M) during horse-riding exercise (normal-walking, fast-walking, running). The study subjects were conveniently sampled from 11 males in their 20s from S horse-riding course who have over 3 years of experience in horse-riding and are licensed as leisure sports instructors (horse-riding), and the following conclusion was drawn. For normal-walking, there was no significant difference of standard energy consumption among waist, wrist, and ankle, and all three locations showed confidence interval with small deviation in Bland-Altman Plot. On the other hand, for fast-walking and running, only wrist showed no significant difference, where only wrist location showed low-deviation confidence interval in Bland-Altman Plot. According to such results, the accuracy was relatively high for wrist-wearing when predicting horse-riding activity energy consumption using accelerometer. Therefore, the wearing location must be considered when predicting horse-riding activity energy consumption with accelerometer on site.

Key words: horse-riding, energy consumption, uniaxial accelerometer, wearing location

Introduction

In general, exercise is achieved through moving one's own body, but in case of horse-riding, it is an exercise that achieves physical activity by indirect influence of horse's movement through communion with the horse. The horse-riding population in Korea has rapidly grown from about 20,000 in 2010 to currently 40,000 in 2015 (MBN, 2015), such that there is increased interest in energy consumption during actual horse-riding exercise, and many sports scientists are conducting research for objective measurement of energy consumption of horse-riding exercise.

Devienne and Guezennec (2000) reported the increase in oxygen intake per horse's walking pattern in the order of normal-walking, fast-walking, and running, and Bong-Ju Seong et al. (2004) used horse-riding simulator to study exercise intensity during horse-riding exercise (MET), which showed the result of increase in the order of normal-walking, fast-walking, and running, with no significant differences by gender. Also, Jun-Geun Park (2013) and Dong-Hwa Yu (2014) researched the energy consumption and exercise intensity according to the horse's walking pattern (normal-walking, fast-walking, running), it was found that the energy consumption and exercise intensity increased in the order of normal-walking, fast-walking, running. The standard

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Correspondence : ksme_@naver.com

measurement instrument used commonly in the above precedent studies is respiration gas analyzer, which is employed as the standard due to its high accuracy of physical activity measurement (Treuth et al., 2004; Trost et al., 2006; Harrell et al., 2005; Schmitz et al., 2005; Pfeiffer et al., 2006). It is costly, however, and is limited location-wise, and also requires specialized knowledge for physical activity measurement such that it is limited in measuring many persons on site (Murphy, 2009).

For such reason, on site, many use accelerometers (ActiGraph, etc.), which is easy to use, is smaller-sized, and can be worn for a long time (Chen & Bassett, 2005). This accelerometer has been verified of its validity as a physical activity inspection instrument through high correlation with standard energy consumption (Lyden, Kozey, Staudenmeyer, & Freedson, 2011; Trost et al., 1998; Pate, Almeida, Mclver, Pfeiffer, & Dowda, 2006; Tanaka, Tanaka, Kawahara, & Midorikawa, 2007). The accuracy of energy consumption prediction according to accelerometer wearing location is, however, reported differently per each researcher (Liao, L. T., Shiang,, T. Y., & Chang, J. H., 2008, Swartz, Strath, Bassett, O'brien, King & Answorth, 2000). Dong-Won Kang, Jin-Seung Choi, Gyeong-Ryul Mun, Yun-Hwan Bang, Gye-Rae Tak (2009) studies the correlation between standard energy consumption and triaxial accelerometer attached to waist and ankle, and as the result, waist showed higher correlation than ankle did. Also, in the study by Liao, L. T., Shiang,, T. Y., & Chang, J. H. (2008), the correlation was high in the order of wrist, waist, ankle, and as such the dispute on the appropriacy or accuracy about the wearing location.

So far, most of the accelerometer studies conducted domestically/overseas had the accelerometer worn at the waist, and the validity verification in the lab environment or everyday environment. Horse-riding activity, however, involves activity with animals unlike on-ground activities, so a method is in need which can accurately measure pure energy consumption of people while excluding the influence of other variables. Therefore, this study intends to verify the accuracy of energy consumption of portable respiration gas analyzer (K4b2), which is the standard inspection instrument, and the energy consumption according to wearing location of uniaxial accelerometer (GT1M) during horse-riding activity, based on which a method to measure horse-riding activity energy consumption on site accurately and conveniently.

Study Method

Study Subject

The study subjects were convenience-sampled as those who can perform protocols of various intensities after wearing portable respiration gas analyzer and accelerometer during horse-riding exercise. The selection criteria was limited to males in their 20s, with over 3 years of horse-riding career, and licensed as leisure sports instructors (horse-riding). Those who cannot freely perform normal-walking, fast-walking, or running during horse-riding may apply unnecessarily excessive force to the body, leaning the body to one side, which may make them unable to receive the rhythm of the horse and have the risk of falling accidents, so only experienced riders with horse-riding abilities were selected. Total of 15 persons participated in the study, but 2 persons who displayed voluntary will to discontinue due to side effects of wearing respiration gas analyzer despite being experience horse-rider and 2 persons whose respiration gas analyzer data was omitted midway were excluded, so that in the end, the data of 11 persons (average age 25.6 years old) were used in analysis. The study subjects participated voluntarily after sufficiently hearing about the purpose and contents of this study beforehand, and the physical characteristics of the study subjects are as in <Table 1>.

Table 1. *Demographic characteristics*

	Horse-riding experience (yr.)	Age (years)	Height (cm)	Weight (kg)
Male (n=11)	5.18±2.89	25.6±3.3	178.7±8.7	70.0±11.74

Experiment Design and Procedure

This study took measurements at an indoor show ring of 25m x 37m since 9AM, and the temperature (°c) of indoor show ring at measurement was 25~31, humidity 60~65%. Also, a single horse was used for all study subjects for measurement validity, and to compare the energy consumption according to accelerometer wearing location during horse-riding activity, horse-riding pattern was categorized into three kinds (normal-walking, fast-walking, running). Normal-walking is the slowest and most comfortable walking pattern of the horse, travelling at 110m per minute, a four-step walking pattern where each of the four legs land on the ground one by one in order (KRA, 2010). Fast-walking occurs when walking faster than normal-walking, travelling at 220m per minute, 15km/h, a two-step walking pattern where two legs symmetrically alternate (KRA, 2010). Running occurs when the horse runs relatively fast, travelling at 340m per minute or 25km/h or over, a 3-step pattern made of symmetrical 3-beat (KRA, 2010).

On the study subjects, portable respiration gas analyzer (K4b2), the standard inspection instrument for energy consumption measurement, were attached, along with uniaxial accelerometer (GT1M) to three body parts (waist, wrist, ankle). Per horse-riding pattern (normal-walking, fast-walking, running), 6 minutes of activity was executed, and 6 minutes of breaks were taken in between the activities. In order to use the steady-state data for the analysis, the 3 minute (3-5minute) energy consumption and counter per minute for each activity were used in the analysis.

Measurement Instrument

1) Energy consumption measurement using portable respiration gas analyzer

Standard energy consumption was measured with breath by breath method using Cosmed $K4b^2$ is a lightweight (925g) measurement instrument, worn on the back of the subject, that can monitor oxygen respiration (VO_2), carbon emission (VCO_2), ventilation (VE) and such while performing physical activities even in an environment other than controlled lab (Mi-Hyeon Lee, Dae-Hyeon Kim, Deok-Hyeon Nam 2012; Eisenmann, Brisko, Shadrick & Welsh, 2003; McLaughlin, King, Howley, Bassett & Ainsworth, 2001). It is currently widely used as the absolute standard in on-site-based validity studies (Gyeong-Ok Lee, Ho-Nam Lee, Hye-Ja Jeon, Hang-Mi Jin, 2006). In order to secure measurement reliability, the pre-measurement calibration was executed in the order of Room air–Gas–Delay-Turbine according to the user manual, and it was used to measure not only the steady-state energy consumption but also energy consumption during all activities stipulated as horse-riding activity types.

2) Energy consumption measurement using accelerometer

For accelerometer, GT1M uniaxial accelerometer (ActiGraph LLC, Fort Walton Beach, FL) was used. Recently, there is an increasing number of users of triaxial accelerometer, which consider the up-down, forward-backward, left-right movements, but according to the study by Mi-Hyeon Lee et al. (2012), it was reported that in adults, the correlations between standard measurement instrument and uniaxial/triaxial accelerometer were respectively r=.877. and r=.880, showing that both types of accelerometer had very high correlation. The uniaxial accelerometer used in this study (GT1M) uses the microelectromechanical system (MEMS), which measures and records the time of acceleration changing in the range of 0.05-2.5G, and takes a measurement of acceleration change every 30Hz (Sasaki et al., 2011). The continuous signal generated as the result is digitized and recorded according to the configured data summary period. Accelerometer is capable of long-term energy consumption cumulative measurement, and is employed in various physical activity measurement studies (Mi-Ja Lim, Gyeong-Suk Kim, 2001). In this study, the data summary period of accelerometer was set to 60 seconds based on the precedent study of Freedson et al. (1998), and the formula of Freedson et al. (1998), which is the uniaxial accelerometer estimation formula of ActiLife6 software, was used to convert ‘activity count' value to calorie per minute. During measurements, the accelerometer was fixed with elastic bands to the three body parts (waist, wrist, ankle) such that it would not move.

Data Processing

In this study, descriptive statistics was applied to the data for physical characteristics. For mean absolute percent errors (MAPE), the difference between predicted energy consumption and standard energy consumption was divided by standard energy consumption and then multiplied by 100. The difference between energy consumption according to horse-riding pattern (normal-walking, fast-walking, running) using standard inspection instrument of portable respiration gas analyzer (K4b^2) and physical activity per wearing location of uniaxial accelerometer (GT1M) was verified by executing one-way ANOVA, and for post-verification, Bonferroni method was used. For the above data analysis, SPSS ver. 21.0 statistics program for Windows was used. As for the estimate error of energy consumption observed by standard measurement instrument and physical activity estimated by each accelerometer, the confidence interval (CI) was checked using Bland & Altman Plot, where Medcalc ver. 14 was used. For all data, the statistical significance level was set to α=.05.

Result

Energy consumption per exercise intensity

The energy consumption measured by standard measurement instrument K4b^2 and activity counts measured by uniaxial accelerometer have the mean / standard deviation per exercise intensity as shown in <Table 2>. A closer look shows that as the horse-riding intensity increases, standard energy consumption and accelerometer activity counts also increase.

Table 2. *Energy consumption per horse-riding activity*

	standard energy consumption (kcal·min^{-1})	waist (kcal·min^{-1})	wrist (kcal·min^{-1})	ankle (kcal·min^{-1})
Normal-walking	2.63±0.57	2.69±0.20	2.87±0.27	2.73±0.13
Fast-walking	6.00±2.98	12.77±7.28	7.28±1.22	10.65±2.76
Running	8.75±2.65	19.70±1.14	9.71±2.55	17.53±1.14

Error rate (%) of energy consumption per exercise intensity and wearing location

The result of substituting percentage error into the formula to verify the accuracy of energy consumption per exercise intensity and wearing location is as shown in <Table 3>. The result of percentage error between the energy consumption collected by standard measurement instrument and energy consumption predicted per exercise intensity and wearing location was found to be ankle 18.33%, waist 18.73%, wrist 19.54% for normal-walking, showing similar error rate for all three parts. For fast-walking, however, it was found to be wrist 55.43%, ankle 94.02%, waist 140.97% and for running, it was wrist 23.18%, ankle 115.00%, waist 144.27%, where ankle and waist showed a large error rate, and finally the wrist error rate was relatively the lowest.

Table 3. *Error rate per horse-riding activity*

	Waist error rate (%)	Wrist error rate (%)	Ankle error rate (%)
Normal-walking	18.73±21.78	19.54±20.44	18.33±23.46
Fast-walking	140.97±66.09	55.43±25.85	95.02±48.79
Running	114.99±72.87	23.18±22.49	114.99±55.54

Table 4. *Energy consumption per wearing location while normal-walking*

	energy consumption ($kcal \cdot min^{-1}$)	F	p
Standard energy consumption	2.63 ± 0.67	1.005	.400
Waist energy consumption	2.69 ± 0.20		
Wrist energy consumption	2.87 ± 0.27		
Ankle energy consumption	2.73 ± 0.34		

Table 5. *Energy consumption per wearing location while fast-walking*

	energy consumption ($kcal \cdot min^{-1}$)	F	p	post-hoc
Standard energy consumption (A)	6.00 ± 2.98	20.696	<.001	A<B, D
Waist energy consumption (B)	12.77 ± 1.55			
Wrist energy consumption (C)	7.28 ± 1.22			
Ankle energy consumption (D)	10.65 ± 2.76			

Values are M±SD. (n=11)

Table 6. *Energy consumption per wearing location while running*

	Energy consumption ($kcal \cdot min^{-1}$)	F	p	post-hoc
Standard energy consumption (A)	8.75 ± 2.65	82.711	<.001	A<B, D
Waist energy consumption (B)	19.70 ± 1.14			
Wrist energy consumption (C)	9.71 ± 2.55			
Ankle energy consumption (D)	17.53± 1.14			

Values are M±SD. (n=11)

Verification of differences in energy consumption per wearing location during normal-walking

<Table 4> is the result of one-way ANOVA conducted in order to see the differences between standard energy consumption and energy consumption of waist, wrist, ankle during normal-walking. The F statistic was 1.005, such that normal-walking did not show a statistically significant difference by wearing location. The mean difference limit was checked by Bland & Altman Plot with 95% confidence interval, and as the result, all three wearing locations included 0, showing an even distribution.

Verification of differences in energy consumption per wearing location during fast-walking

<Table 5> is the result of one-way ANOVA conducted in order to see the differences between standard energy consumption and energy consumption of waist, wrist, ankle during fast-walking. The F statistic was 20.696, such that fast-walking showed a statistically significant difference by wearing location ($p<.001$). The post-verification showed that the accelerometer worn on the waist and ankle except wrist significantly overestimated energy consumption. The mean difference limit was checked by Bland & Altman Plot with 95% confidence interval, and as the result, as shown in <Figure 2>, only the accelerometer worn on the wrist included 0, showing an even distribution.

Verification of differences in energy consumption per wearing location during running

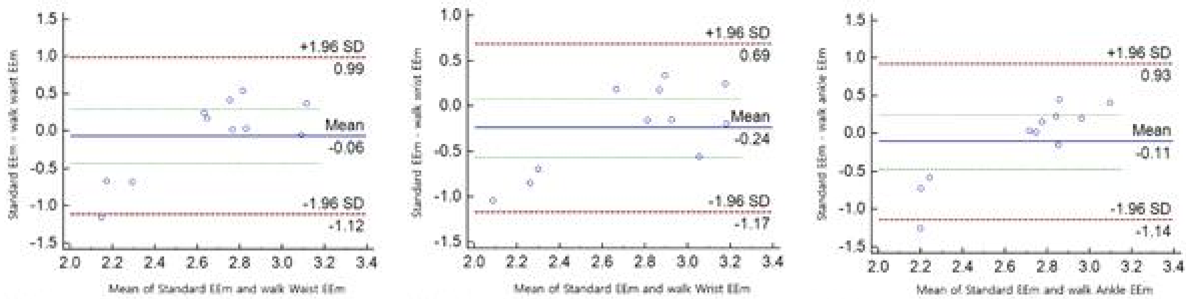

Fig 1. *Bland-Altman Plot of normal-walking standard energy consumption and per-location energy consumption*

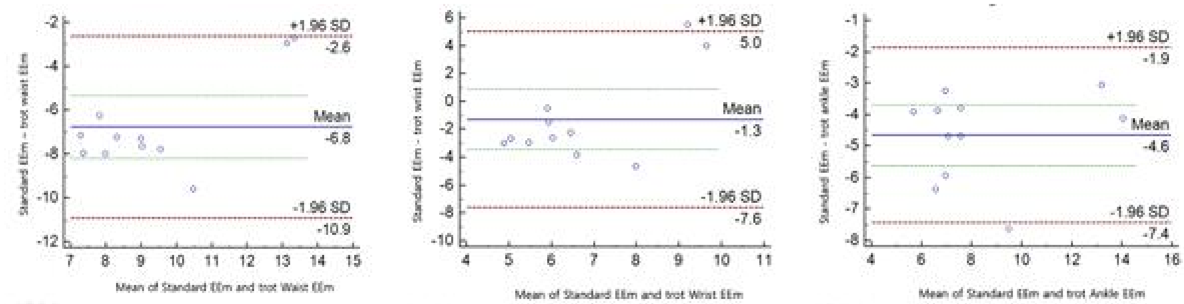

Fig 2. *Bland-Altman Plot of fast-walking standard energy consumption and per-location energy consumption*

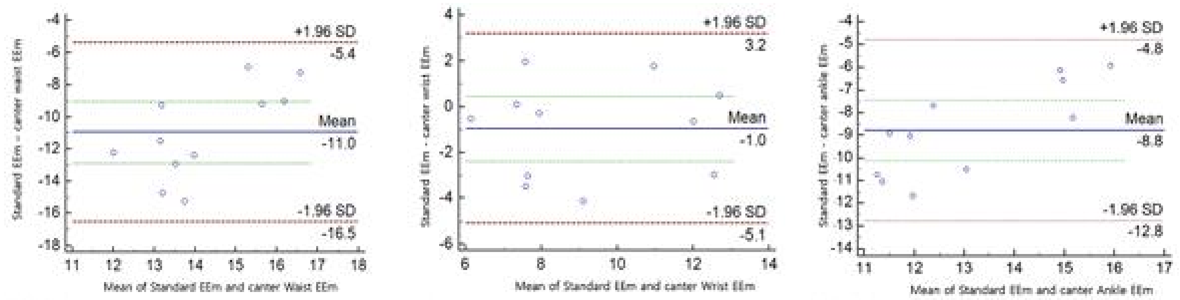

Fig 3. *Bland-Altman Plot of running standard energy consumption and per-location energy consumption*

<Table 6> is the result of one-way ANOVA conducted in order to see the differences between standard energy consumption and energy consumption of waist, wrist, ankle during running. The F statistic was 82.711, such that running showed a statistically significant difference by wearing location ($p<.001$). The post-verification showed that the accelerometer worn on the waist and ankle except wrist significantly overestimated energy consumption. The mean difference limit was checked by Bland & Altman Plot with 95% confidence interval, and as the result, as shown in <Figure 3>, only the accelerometer worn on the wrist included 0, showing an even distribution. Therefore, it was found that when predicting energy consumption during horse-riding activity using accelerometer, wearing it on the wrist shows relatively high accuracy.

Discussion

For NHANES (Nutritional Health and Nutrition Examination Survey), the prominent long-term follow-up study related to physical activity of USA, the physical activity has been measured by wearing accelerometer on the waist in order to improve the measurement accuracy since 2003. In 2012, however, for NNYFS (National Youth Fitness Survey), which surveyed the physical activity and physical fitness level of children and youth of 3~15, changed the wearing location by placing the accelerometer on the wrist to measure physical activity (CDCP: Center for Disease Control and Prevention, 2012). This was because wearing the accelerometer on the wrist has the advantage in that not only walking/running but also sit-down activities and activities involving the upper body only can also be recognized as energy consumption (CDCP: Center for Disease Control and Prevention, 2012). The discussion, however, about the accuracy per wearing location continues among researchers.

In this study, 11 males in their 20s who have over 3 years of horse-riding career and are licensed in leisure sports instructor (horse-riding) were taken as the study subjects, and the energy consumption during horse-riding activity per wearing location of uniaxial accelerometer (GT1M) was measured, which was compared and analyzed against standard inspection instrument of portable respiration gas analyzer (K4b2). The study results are as follows.

The energy consumption measured at waist, wrist, ankle for normal-walking, and wrist for fast-walking/running made predictions similar to the standard energy consumption. Such results are thought to be due to the characteristics of horse-riding activity where the action occurs sitting on top of the horse.

Horse-riding is an activity where horse and man must come together as one both physically and mentally. Nevertheless, excluding the horse's movement and focusing on the human movement only, horse-riding involves weight movement, leg hand stamp, and fist control on the human part to become one with the horse (KRA, 2010). Here, the weight movement refers to the waist part, and as the center of horse and center of human body must be in agreement without being disturbed by the forward/backward and left/right movement of the horse (KRA, 2010), one must receive the rhythm of the horse as is. Here, in the process of receiving the horse's rhythm at the buttocks and delivering it to the waist, it is thought that the horse's activity and the person's activity are measured together, which renders the waist measurement to be closer to the horse's activity rather than the person's activity. This is in agreement of the result by Jun-Geun Park (2013) where in the validity verification of energy consumption measurement device during horse-riding, energy consumption was found to be overestimated as the result of comparing uniaxial accelerometer (GT1M) and triaxial accelerometer (GT3X) worn on the waist against K4b2.

The hand stamp of leg refers to ankle; first of all, the vibration from the horse's rhythm goes through the thigh and calf and is indirectly delivered, so the activity from horse's rhythm is reduced, but as the role of the hand stamp is to cover the horse's belly using thigh and calf in order for the person to maintain balance on the horse, while propelling the horse at the same time, which is why it is thought that the human activity is great at that point. This, however, also involves a tight attachment to the horse's body, so it is thought that the horse's and person's activities were measured together.

Finally, fist refers to wrist; during horse-riding activity, the hand grabs onto the rein connected to the bit to control the horse. The bit is connected to the most sensitive mouth of the horse, so must be soft, flexible and delicately controlled. For this reason, wrist is thought to be the part which can measure human activity with minimal influence from the horse's rhythm.

Rawson & Walsh (2010) estimated the energy consumption of resistant exercise and then verified the correlation of activity counts per wearing location (right wrist · waist · ankle) of accelerometer (GT1M) while conducting resistant exercise. The study result showed correlation in the order of waist ($r = 0.77$; $p < 0.001$), ankle ($r = 0.50$; $p < 0.01$), wrist ($r = 0.31$; $p = 0.10$), which is similar to the study result of normal-walking in this study, but there were differences in mid/high-intensity activities of fast-walking and running activities. Also, Rosenberger et al. (2013) attached triaxial accelerometer (wocket) to the waist and wrist and compared the accuracy of physical activity intensity estimation and physical activity type. The study result showed that the accelerometer worn on the waist

(71%~96%) had higher sensitivity and specificity than that worn on the wrist (53% ~76%) did. This partially supported the normal-walking result which showed that waist part was more accurate than the wrist part. Swartz et al. (2000), however, attached CAS accelerometer (model 7164) to the wrist and buttocks of 70 adults (19~74 years of age) and executed slow-walking of 4.6km/h and fast-walking of 6km/h. The study result reported that wrist was 3.3% and waist was 31.7%, showing that the accelerometer worn on the waist made more accurate predictions of energy consumption while walking, which is not in agreement with the results of this study.

The existing studies on accuracy per accelerometer wearing location were mainly protocols related to walking or daily lives, which made it impossible to compare directly to horse-riding activity, which was the subject of this study. Based on the results of this study, however, the accelerometer wearing location must be considered when predicting horse-riding activity energy consumption using accelerometer.

Conclusion

This study measures the energy consumption during horse-riding activity per wearing location of uniaxial accelerometer (GT1M), which was compared to the standard inspection instrument of portable respiration gas analyzer (K4b2), based on which the intent is to verify the accurate and convenient on-site measurement method for energy consumption during horse-riding activity.

To achieve the objective of this study, the standard energy consumption inspection instrument of portable respiration gas analyzer (K4b2) and the uniaxial accelerometer (GT1M) on waist/wrist/ankle were attached, and the measurements were used in the data analysis. Windows SPSS ver. 21.0 was used to execute percentage error per exercise intensity and wearing location and one-way ANOVA RM, and the estimate error was found through Bland & Altman Plot using Medcalc ver.14. The conclusion of this study is as follows.

First, it was found that as the intensity of horse-riding activity increased, standard energy consumption and accelerometer activity counts increased as well.

Second, normal-walking showed no significant difference in all of waist, wrist, ankle against standard energy consumption, and in Bland-Altman Plot, all three parts showed low-deviation confidence interval.

Third, for fast-walking and running, only wrist showed no significant difference, and in Bland-Altman Plot, only the wrist part showed low-deviation confidence interval.

In this study, the relationship of energy consumption during horse-riding activity according to the wearing location of uniaxial accelerometer (GT1M) was clarified. As for follow-up studies, it is necessary to conduct a study related to accuracy verification utilizing wearable devices, etc. which are usually worn on the wrist and also to exercise effect during horse-riding training period.

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