



Doctor, when can I drive? – Range of motion of the knee while driving a car



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ABSTRACT

Background: One of the most important activities of daily living is operating a motor vehicle. With increasing age the prevalence of musculoskeletal disorders such as knee osteoarthritis may interfere with an individual's ability to do so safely. Physicians are tasked with determining a patient's ability to drive and yet the necessary joint range of motion required for driving a car has not been characterized.

Methods: The range of motion of the right and left knees was recorded using electrogoniometers in 20 healthy subjects while driving a car on three route types (a) city streets, b) country roads and c) highways). Special emphasis was placed on the left knee associated with changing a gear.

Results: The range of motion while driving is 40–80° for the right and 20–85° flexion for the left knee. A significant difference was noted for each *side* ($p < 0.01$) with a higher flexion occurring in the left knee ($p < 0.01$). The average position of the knee while changing a gear (beginning, maximum, ending) was: right: $55^\circ \pm 10^\circ$, $62^\circ \pm 10^\circ$, $53^\circ \pm 10^\circ$; left: $67^\circ \pm 7^\circ$, $39^\circ \pm 8^\circ$, $66^\circ \pm 8^\circ$ (mean flexion \pm standard deviation).

Conclusion: This study characterized the knee range of motion that occurs while driving a car. Our data suggests that common driving activities such as accelerating a vehicle or braking can be achieved with the right knee through a limited range of motion. The greater range of motion and the higher flexion of the left knee are mainly attributed to the gear changing. The present data may benefit physicians in their evaluation of driving capability.

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1. Introduction

Musculoskeletal health is essential for people's personal mobility and their ability to actively participate in all aspects of life [1,2]. Driving a car has become an indispensable component of our society. Subsequently, an inability to drive can often result in severe socio-economic implications. Elderly patients will often aim to continue driving and yet this patient group is particularly susceptible to [1] musculoskeletal disorders, such as knee osteoarthritis. Because pain, impaired muscular function or movement restriction of the knee can affect an individual's ability to safely operate a vehicle, traffic safety for the elderly is a growing public health issue [3–6]. For example, the time to return to driving for patients undergoing total knee arthroplasty is still discussed con-

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roversially [7]. Different recommendations ranging from two to six weeks exist [7,8] which are influenced by many factors such as perioperative pain management [9]. Despite improvements in vehicle safety, more than 1.25 million people die each year as a result of vehicular trauma worldwide. Road traffic injuries are the leading cause of death among people between 15 and 29 years of age worldwide and road traffic crashes cost most countries three percent of their gross domestic product [10]. Therefore, physicians bear a great responsibility when evaluating a patient's ability to drive. Guidelines for assessing and counseling older drivers have been created to help physicians address preventable injuries caused by motor vehicle crashes [11,12]. No objective parameters related to the necessary joint range of motion (ROM) exist. Therefore, no evidence based recommendations concerning driving capability and, in particular, knee ROM currently exist. The aim of this study was to quantify the knee ROM that is required to drive a left sided car with manual transmission on: I) city streets, II) country roads and III) highways.

2. Materials and methods

All participants had a valid driver's license and owned their vehicle, which is driven more than 5000 km/year. Exclusion criteria were musculoskeletal or systemic diseases, diseases of the central or peripheral nervous system, pregnancy, chronic drug or alcohol abuse and psychiatric disorders. Most of the participants were employees of the university hospital or students. Each subject completed a standardized questionnaire. An informed consent was obtained prior to the procedure. Approval by the institutional review board was obtained. CE certified electrogoniometers (Twin Axis goniometer type SG 65, Biometrics Ltd., Newport, UK) were used to measure the ROM (flexion/extension) of the knee while driving a car. The work mechanism of these electrogoniometers is based on the measurement of strain changes along the length of a wire. There is a composite wire with strain gauges between the two endblocks. Every time the angle changes between the two endblocks, the change in strain of the wire is measured. The design allows only measurement of angular and not of linear movements. If the endblocks move linear to each other, the output remains constant. The goniometers were attached with double sided medical adhesive tape to the

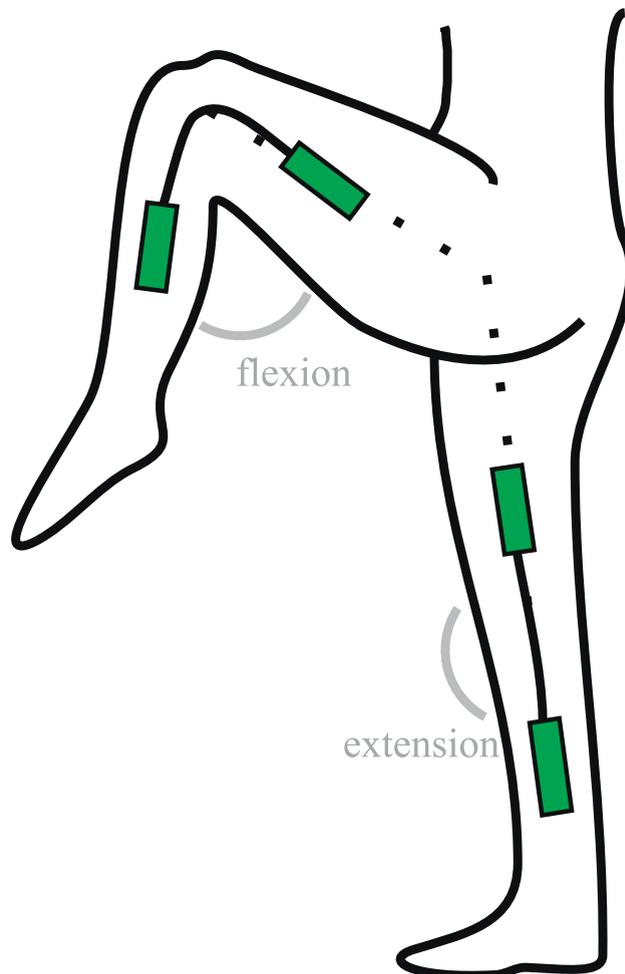


Figure 1. The goniometer was attached to the lateral aspect of the knee.

In case of normality a univariate analysis of variance (ANOVA) with the factors *road type* (city, country and highway) and *side* (right and left knee) was performed followed by post hoc t-tests for independent samples. p values were corrected for multiple testing using the Bonferroni test and values <0.05 being assumed to be statistically significant.

For further analysis, the timeline of each subject of the continuously measured ROM (50/s) with regard to the marked maneuvers was visualized and further investigated. The most common and stereotypical maneuver that was identified is the changing a gear maneuver. Therefore, arithmetic mean and standard deviation of the knee position (flexion/extension) at the beginning, at the maximum amplitude and at the ending of changing a gear were calculated for each subject and 10 actions per subject.

3. Results

In this study, 20 healthy subjects (10 male, 10 female) participated. No one had a history of lower extremity trauma or recent immobilization. The age varied between 23 and 36 years and the mean age was 29.4 years \pm 3.0 years.

3.1. Range of motion

The average possible maximum ROM versus the ROM and the mean flexion of the right and left knees while driving on different road types is shown in Table 1. Figure 3 shows the detailed ROM while driving a car on different road types in a histogram.

The ANOVA revealed no significant main effect for road type ($F(2, 42.31) = 0.51, p = 0.60$) or interactions for road type \times side ($F(2, 83.95) = 1.01, p = 0.37$) but a significant main effect for side ($F(1, 404,760.68) = 4884.63, p < 0.01$) with a higher mean flexion for the left knee compared to the right knee.

3.2. Changing gear

In order to investigate the significant main effect for *side* with a higher mean flexion of the left knee while driving a car, the timeline of the continuously measured ROM (50/s) of each subject was visualized with regard to the marked maneuvers. The most common and stereotypical maneuver that was identified is the changing a gear maneuver (Figure 4).

Arithmetic mean and standard deviation of the knee position (flexion) at the beginning, at the maximum amplitude and at the ending of changing a gear (10 maneuvers per subject) are shown in Table 2.

4. Discussion

Driving a motor vehicle requires muscle strength, endurance, coordination, reaction time and the ability of the extremities to move [14–17]. The American Medical Association (AMA) and the National Highway Traffic Safety Administration (NHTSA) have created an Assessment Of Driving-Related Skills (ADReS) that include recommendations regarding 1) vision, 2) cognition and 3) motor/somatosensory function [6]. A broad range of vision and cognition tests exist to determine driving capability [11,18–20]. In contrast, only a few motor/somatosensory tests have been described and these ask the patient to either mimic the act of driving or to perform different movement tasks e.g. neck rotation, shoulder and elbow flexion or ankle plantar flexion/dorsiflexion. The examiner uses a crude scoring system: Within normal limits, not within normal limits, good range of motion with excessive pain or very limited range of motion [11]. To the author's knowledge, no study has quantified the knee range of motion required to drive a car and yet it may be desirable to combine joint range of motion with ADReS when attempting to determine driving capability. A previous study has successfully characterized range of motion of the right wrist while driving a car [14]. The goal of this study was to measure the mean range of motion of the knee while driving a car based on quantitative noninvasive measurements using electrogoniometers.

We have shown that during all our driving maneuvers the right knee moves through a very limited ROM between 40° and 80° flexion. The left knee operates through a larger ROM between 20° and 85° flexion which is a significantly higher mean flexion than the right knee. No significant differences were found between the different route types. In this study, only left sided cars with a typical right sided manual transmission were used. In this setting, subjects hold their left leg in a highly flexed knee posture with the foot comfortably positioned on a footrest (knee flexion while changing a gear: beginning: 67° \pm 7°, Table 2) and only while changing a gear is the clutch depressed with the left leg, which results in a very low flexed angle of the knee (knee flexion while changing a gear: maximum: 39° \pm 8°, Table 2). In contrast, subjects maintain speed by pressing the accelerator with their right leg and only while changing a gear do they take their

Table 1

The average maximum ROM of the knee and the mean flexion of the knee (\pm standard deviation) while driving on different road types.

	Maximum ROM	ROM while driving		
		(a) City	(b) Country	(c) Highway
<i>Right knee</i>				
Flexion	(–)1–118°	40–80°	40–80°	40–80°
Mean flexion		56° \pm 10°	55° \pm 9°	55° \pm 10°
<i>Left knee</i>				
Flexion	(–)1–120°	25–85°	25–85°	20–85°
Mean flexion		58° \pm 11°	63° \pm 8°	62° \pm 7°

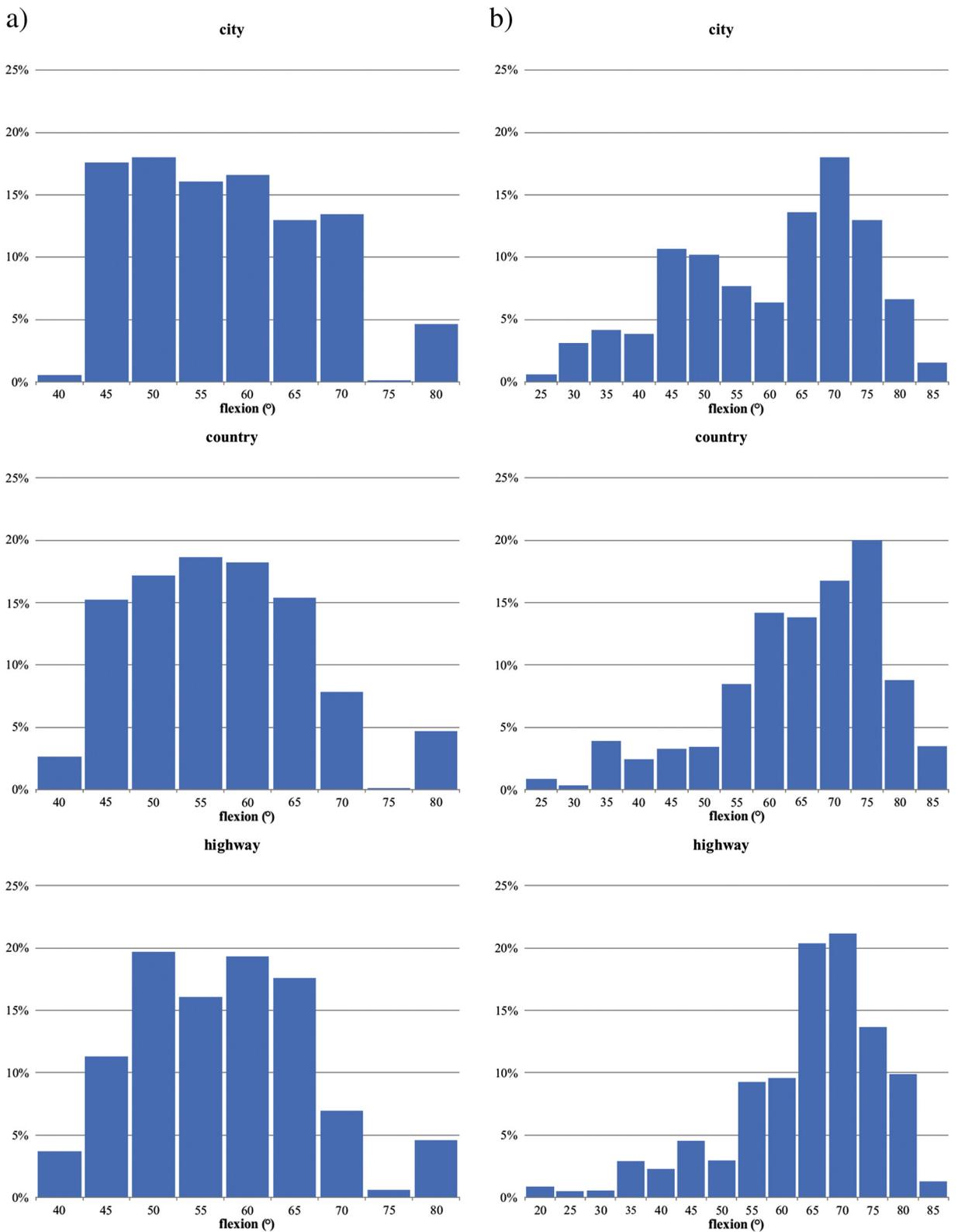


Figure 3. Histogram of the ROM (flexion) of the a) right and b) left knees while driving on city roads, country roads and highway.

Changing gear

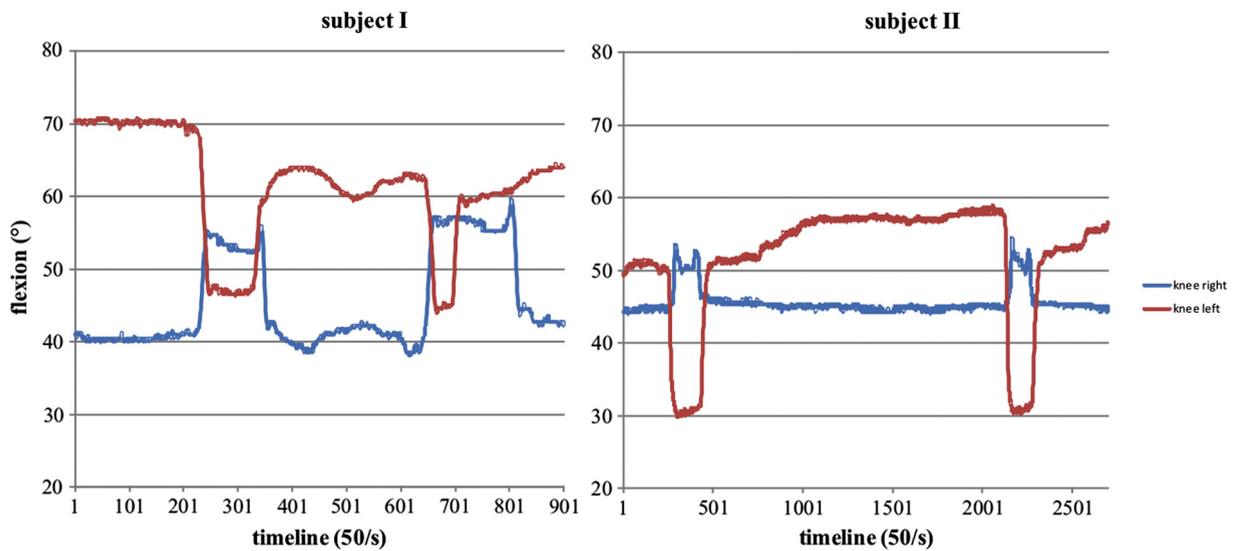


Figure 4. Example of the ROM of the right and left knees of two subjects while changing a gear twice.

right leg off the accelerator which results in a short period of higher flexion (Table 2). This could explain the greater ROM and significantly higher flexion of the left knee when compared to the right (Figure 4). With the right leg, subjects had to accelerate, maintain speed and hit the brake. The act of accelerating and using brakes has been investigated with observer reported outcomes such as response time, total brake time or required brake force [21–24]. Our data suggests that these important maneuvers can be achieved within a very small ROM within 40° and 80° flexion. In contrast, Dammerer et al. showed that movement restrictions of the right knee with a brace set to a ROM of 0° to 90° flexion already showed a significant effect on the brake response time (607 ms) in comparison to the subjects without a brace (594 ms) [24]. The authors point out, that there is no evidence to quantify the relationship between the measured increase of brake response time and the risk of an accident. In line with that, Green described, that when a person is fully aware of the time and location of the brake signal, drivers can detect a signal and move the foot from accelerator to brake pedal in 700 to 750 ms [25]. The significant increase of response time caused by a knee cast measured by Dammerer (594 vs. 607 ms) is still within the range measured by Green, and, therefore, should not influence driving capability significantly. These results support our hypothesis, that a car braking maneuver can be achieved within a small ROM located between 40° and 80° flexion as was measured in our study. The important influence of musculo-skeletal pain on driving ability has not been measured and further studies are needed to investigate its contribution [26,27].

A limitation of our study is that only left sided cars with manual transmission were used. Whether the transmission is manual or automatic should not have a substantial influence on the ROM of the right knee which is mainly used for acceleration, maintaining speed and applying the brakes. These maneuvers would be the same in cars with a manual or automatic transmission. ROM of the left knee would likely change in the setting of an automatic transmission, because subjects may choose to position their left leg in a more comfortable flexed position as they do not have to depress the clutch while changing a gear. For that reason, the ROM of the left knee would, likely, be smaller and demonstrate a higher mean flexion than in this study. The steering wheel location on the left or right side should not matter to the lower extremities because the pedals have the same arrangement in both car types. Another critical aspect is that only the knees of healthy subjects with non-painful adjacent joints were measured. Movement restriction of the ankle must be compensated by the knee [28] and this could result in greater knee ROM requirement. To investigate the influence of the synergistic equilibrium of hip, knee and ankle on the driving capability, further studies are needed.

5. Conclusion

The present study has characterized the knee range of motion that is commonly required to drive a car. Our measurements suggest that common driving activities such as accelerating or braking can be achieved with a limited right knee arc of motion

Table 2

The average position of the knee while changing a gear at beginning, at maximum and at the ending (\pm standard deviation).

Side	Knee flexion while changing a gear		
	Beginning	Maximum	Ending
Right knee	55° \pm 10°	62° \pm 10°	53° \pm 10°
Left knee	67° \pm 7°	39° \pm 8°	66° \pm 8°

between 40° and 80° flexion. The greater range of motion between 20° and 85° flexion and the significantly higher mean flexion of the left knee are attributed to the motion requirements of changing a gear. These ranges of motion may be used by the physician to assist in the determination of driving capability. Future studies that quantify the range of motion of adjacent lower extremity joints may foster our understanding of the complex interplay between joints while driving.

Conflict of interest

The authors declare that they have no competing interests.

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Human and animal rights

There is a positive vote from the ethics committee of the Medical Faculty.

Informed consent

Prior to subject's participation, written informed consent was obtained.

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