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# Artifact-User Affordances versus Artifact-Artifact Affordances Applied to Graft Placements during Knee Reconstruction

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## ABSTRACT

Recently, personalized medicine applied here as individualized surgery, which represents the customization in insertion sites, size of the graft, tunnel placement and graft tension for each individual patient, has been proposed. A question is whether the surgeon's task defines the level of analysis. The alternative presented here proposes the viewpoint of understanding the affordances of the knee as a means to influence the user. This study sought to offer a design method supporting knee reconstruction surgery, affording an approach for the user/surgeon/therapist. This explains how perceivers *judiciously pick up* the instantaneous knee screw (IKS) as haptic information for perceiving affordances. For shank and thigh, must compound into a screw on IKS, whence walkers perceive affordances of the cylindroid. Thus the cylindroid must become a familiar conception with the students of the affordance-based surgical design.

**Keywords:** Self turning system of the knee, ACL impingement, Knee synergy, Instantaneous knee screw (IKS), Invariant screw, Information pick-up, Gibsons affordance-based surgical design

## INTRODUCTION

The anterior cruciate ligament (ACL) is a critical knee joint, bone-to-bone connected, stability ligament, which is attached from an anterior location of the proximal tibia to a posterior location of the distal femur. Proper positioning of the ACL graft has been proven to be of paramount importance for graft longevity. Malposition of the ACL graft, in the anterior placement of the tibial tunnel, was associated with roof impingement. Roof impingement of the reconstructed ACL graft was recognized early as a significant factor that leads to graft failure [1].

Recently, personalized medicine applied here as individualized surgery, which represents the customization in insertion sites, size of the graft, tunnel placement and graft tension for each individual patient has been proposed [2]. A critical decision-making issue pertains to the surgeon's placement of a tibial-femoral tunnel so as to mimic the native orientation of the ACL attachment [2]. Thus, the surgeon's concern has to do with particular aspects of the local anatomy and, thus, by extension, the particular biomechanical artifacts that can be manipulated by the surgeon. A question is whether the surgeon's task defines the level of analysis. The alternative presented here proposes the viewpoint of understanding the affordances of the knee as a means to influence the user.

The affordances of a product are what it provides, offers, or furnishes to a user or another product. Affordance links perception to action, as it links a creature to its environment. The concept of affordance implies a special approach to psychology, particularly to perception-the ecological approach [3]. We applied Gibson's concept of affordance to the design of artifacts in general and, in particular, to the domain of anatomic artifacts having a biomechanical influence. Gibson demonstrated how human (and animal) perception and motor control is continuous with interactions between inanimate physical systems [3]. The point of view of this paper is functional, in the old sense, but also in a modern sense that incorporates systems theory.

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In the context of engineering design, an affordance was defined as a relationship between two subsystems in which a potential behavior can occur that would not be possible with either subsystem acting in isolation [4]. Maier and Fadel coined the term artifact-artifact affordance (AAA). These affordances between artifacts and the people that use them are called artifact-user affordances (AUA). For example, the gear pair (**Figure 1(a)**) is referred to as an artifact-artifact affordance (AAA) for uniform, continuous motion transmission between two parallel axes, which we will call "resonance" or "tuning", and it is possible only if the line of action passes through a fixed point, known as the pitch point. The trajectory and resting pitch point are not monitored and adjusted (Recall that neither joint 'gear' perceives the other gear) but simply conjugate uniform motion transmission by virtue of their structure, the principle of structural influence behavior [5].

However, the limbs and extremities are, of course, motor organs as well as sensing organs, but the function of motor performance can be subordinated to the task of exploratory adjustment in the case of the limbs. This "resonance" or "tuning" of the perceptual system in **Figure 1(b)** to environmental information is different from the resonance of a gear pair, as shown in **Figure 1(a)** since these are fixed and will only resonate to a specific kind of their structure-a particular gear profile.

The aim of this study is to identify the measurable invariants as a basis for structural placement of the tunnel during ACL reconstruction as a positive affordance-based design. We drew on a surgical technique as an example of how the theory of affordances may be utilized for high-level affordance-based design by customizing the placements of the tunnel during the reconstruction of the anterior cruciate ligament.

## MATERIALS & METHODS

It is not often realized that it is the function of a joint to not merely permit mobility of the articulated bones, but also to register the relative position and movement of the bones. Information about things and events exists in ambient arrays of energy. Actions have consequences that turn up new information about the environment. They also provide information about the actor-about where he is, where he is going, what he is doing. All actions have this property, but it is useful to distinguish executive action from action that is information-gathering. Other scientists also made an extension of a distinction James Gibson made between two modes of activity: exploratory and performatory. Without this distinction, psychologists will forever be separating into camps–one a group of objectivists, the other a group with subjectivist sympathies.

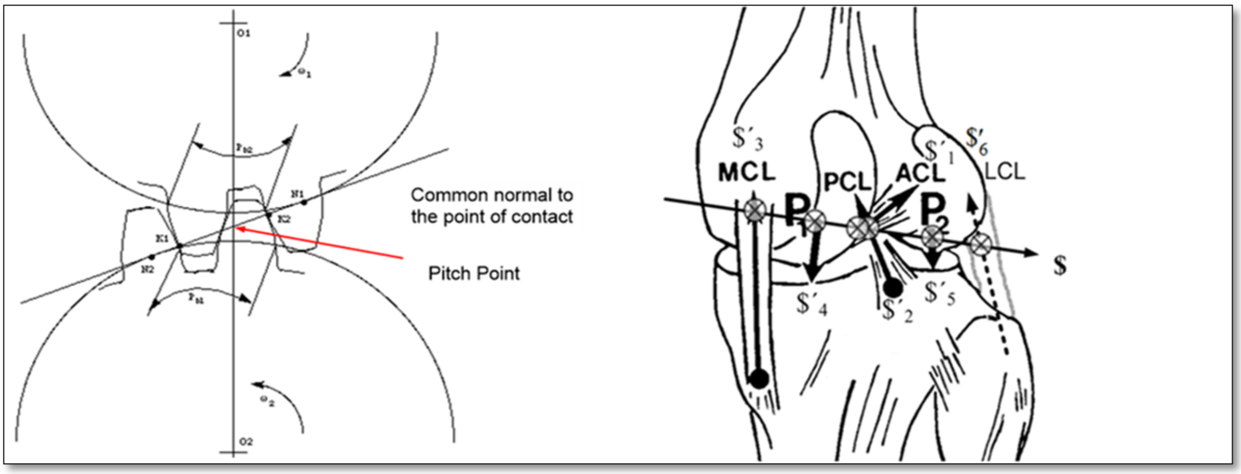


**Figure 1. a)** The artifact-artifact conjugate action as presented in the form of two interacting gears to demonstrate the uniform motion transmission between two parallel axes as may be found in a knee joint. **b)** The coordinative structures of knee synergy as represented by six constraints ($\$'_i, i = 1,..,6$),which are collectively reciprocal to the instantaneous knee screw($) as indicated by their intersections (at the $\otimes$'s). A force balance is indicated when the virtual coefficient vanishes as the necessary and sufficient condition for knee equilibrium.

We do not simply gait, we walk. The knee system is a motor system, as well as a sensory one. Perception occurs over time and is active. Action participates in perception. Active adjustments in the sensory systems are essential. But action itself may be informative, too. It was developed in detail by Gibson– e.g. in his experiments on active touch [6]. Perception is a self-tuning process, in which the pick-up of environmental information is intrinsically reinforcing so that the system self-adjusts so as to optimize its resonance with the environment: "A system `hunts' until it achieves clarity", wrote Gibson, a little like the scanning of a modern digital tuner [7]. We perceive affordance of the ground to be walked on.

> The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment [3] (Gibson 1979), p. 127.

We proposea self-tuning system of the perceptual organ of the knee where six constraints ($) are collectively reciprocal to the instantaneous knee screw (IKS or $) indicated by ⊗ (**Figure 1(b)**).

Recently, the self-tuning system of the perceptual organ of the knee approach proposed herein was validated experimentally [8]. That study experimentally described the invariant of the self-tuning system of the knee (STSK) by measuring whether all the lines of action intersect at the IKS ($) following natural knee motion, resulting in the mean distances between each constraint line of action and the IKS staying below 3.4 mm and 4.5 mm for ex vivo and in vivo assessment, respectively (**Figure 2(b)**). At issue is how an affordance level of analysis is referred to as the STSK?

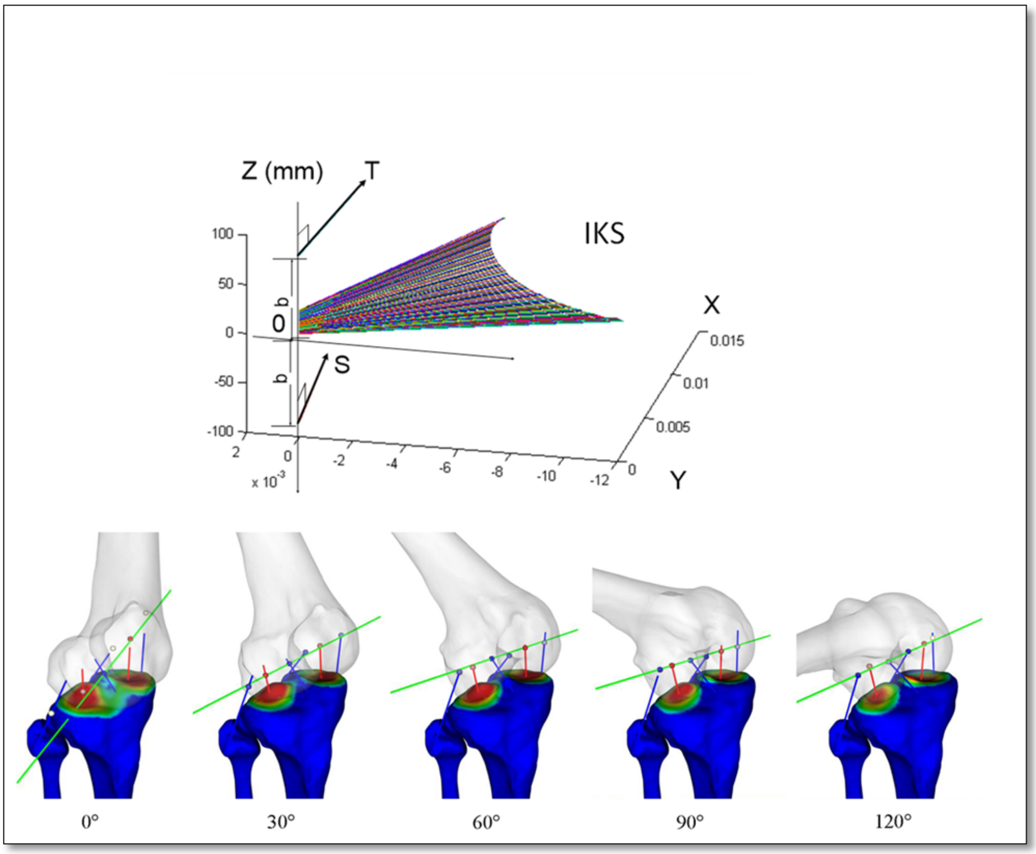


**Figure 2. a)** An exemplar Ball-Disteli diagram [24] representing two generally disposed screws (T and S or and) and conveniently placed on the z-axis along their common perpendicular with the half distance. The origin of coordinate is halfway between the screws, and the x-axis is equally inclined by the angle between the screws. An instantaneous knee screw (IKS) that is linearly dependent on the screws during any point of knee movement can be expressed as such after normalization. The Ball-Disteli diagram aligns itself using the principle of three axes. **b)** Representation of the IKS (green line) and the lines of action of the ligaments (blue lines) and cartilage contact (red areas and red lines) for wrenches identified every 30° within the range of knee motion for a representative subject. The white or colored dots represent the closest point to the IKS for each wrench. The colors range from white (di > 5 mm) to the color of the corresponding intersecting line (di = 0 mm). Cartilage contact colors on the tibia are proportional to the tibial-femoral relative separation distance (red: distance ≤ 0 mm; blue: distance > 7 mm). The original anatomic schematics and lines of action were published previously (Conconi, Sancisi et al. 2019) and are used by permission of Professor Michele Conconi.

## RESULTS

As described, we identified the measurable second-order invariant of knee synergy and proposed it as a new view of the basis of tunnel placement (**Figure 1(b)**). The knee synergy approach identifies the information as a means to perceive the affordance of uniform motion transmission. To apply the described approach and identify the invariant, we characterized the shank to the thigh (the tibia to the femur) relative motion, i.e., the second-order invariance of the knee synergy. These results were then compared with experimental data for validation as provided by the "Grand Challenge Competition to Predict *In Vivo* Knee Loads" as part of the Symbiosis project funded by the National Institutes of Health [9]. The IKS is defined in terms of the second-order invariant by a linear combination of the two screws of the first-order invariant, S and T, instantaneous screw axes of the shank and thigh (**Figure 2(a)**) [10]. Then the IKS must be a screw that has been picked up from the many candidate screws on the cylindroids [11], which is reciprocal to STSK (**Figure 1(b)**). Hence, the ratio of the amplitudes about S and T, (S, T) may be determined (**Figure 2(a)**), which manifests the fact that the sensitivity of the knee joint to its disposition is of crucial importance in picking up perceptual information. **Figure 3** shows that the deterministic character of (S, T), the ratio of the angular velocity (unit of rad/0.05 sec) of the two limb segments, the shank and thigh, involving at the knee joint.

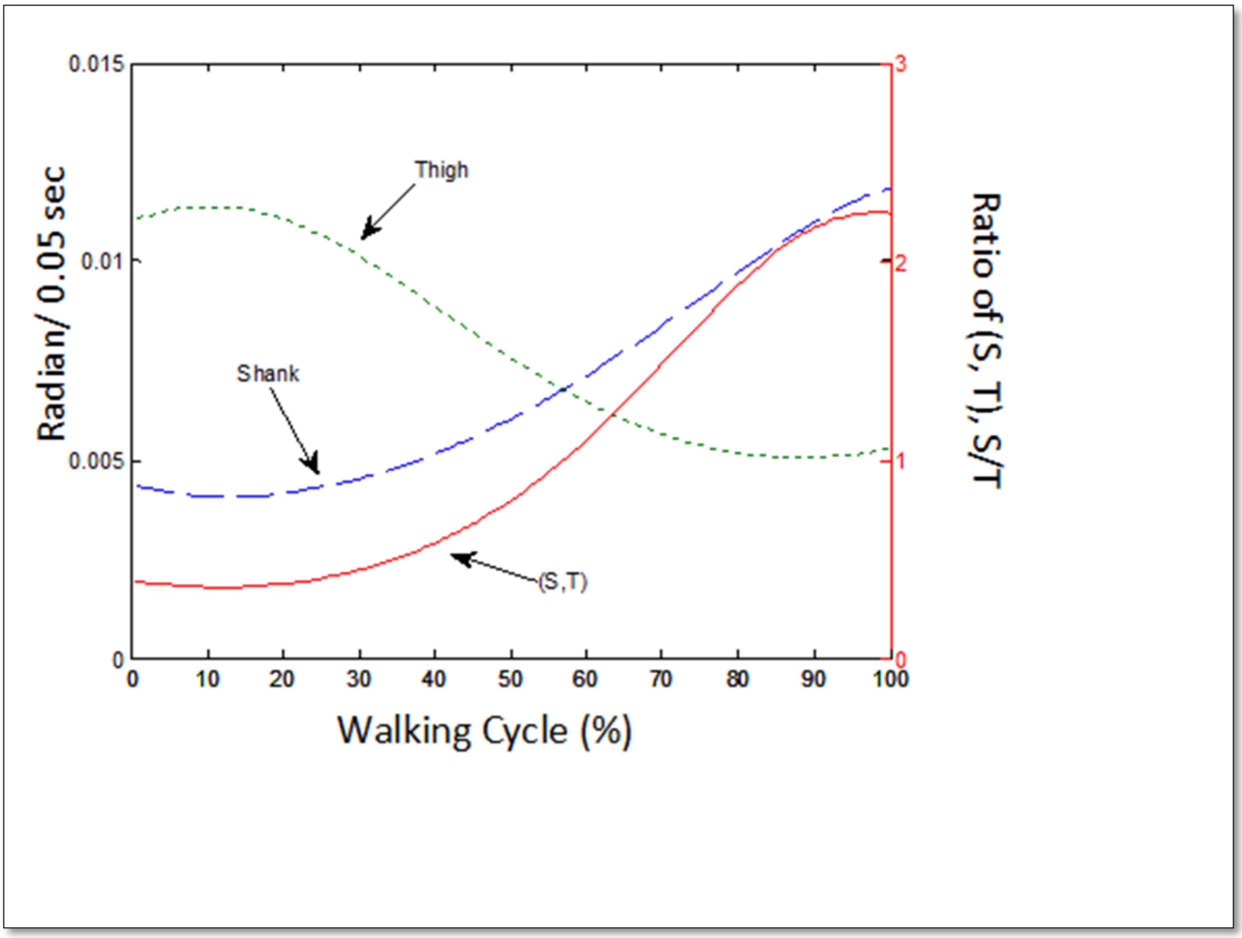


**Figure 3.** If this intermediate screw, the IKS be given, the ratio of the amplitude of the twists on the given screw (S, T) is determined.

To validate our ecological approach to perception and motor control during the stance phase of a gait, we used previously published experimental datasets [9] and compared their measured medial and lateral contact forces with our predicted datasets [12]. Predicted and measured values of constraint forces at the lateral contract are compared with the RMS error being 148.1 N [12]. Available data included limb motion capture, fluoroscopy images, GRFs, electromyo graphical readings determining muscle forces, as well as medial and lateral knee contact forces derived from GRFs. Data were collected from an instrumented right knee reconstruction in an adult male subject (65 kg mass and 1.7

m height). When the variations in the ground contact patterns (magnitudes and direction) are shown along with the variations of knee movement in terms of IKS, the STSK-is uniquely determined by the two corresponding pairs (**Figure 4**).

The IKS was determined by a linear combination of two instantaneous screw axes of the shank and thigh (**Figure 3**). The IKS is shown to nearly coincide with a reciprocal screw of the GRF, as indicated in a magnified inset image (**Figure 4**). Expressing this differently, the DOF of instantaneous screws and the constraints of impulsive screws are projective, where virtual work is done on the IKS should vanish and merge into the STKS directly or instantaneously. The statement that there are no constraints to such a system is merely a different way of asserting the obvious proposition that when a body is perfectly free, it cannot remain in equilibrium if the forces which act upon it have a resultant. This reciprocity is captured by the concept of a mutuality relationship between the constraints and the DOF [13, 14]. Information about the subject accompanies information about the environment. Here it is shown that ego reception accompanies exteroception; subjective and objective information is available to specify both characteristic poles. One pole perceives the environment, and other pole co-perceives itself [3].

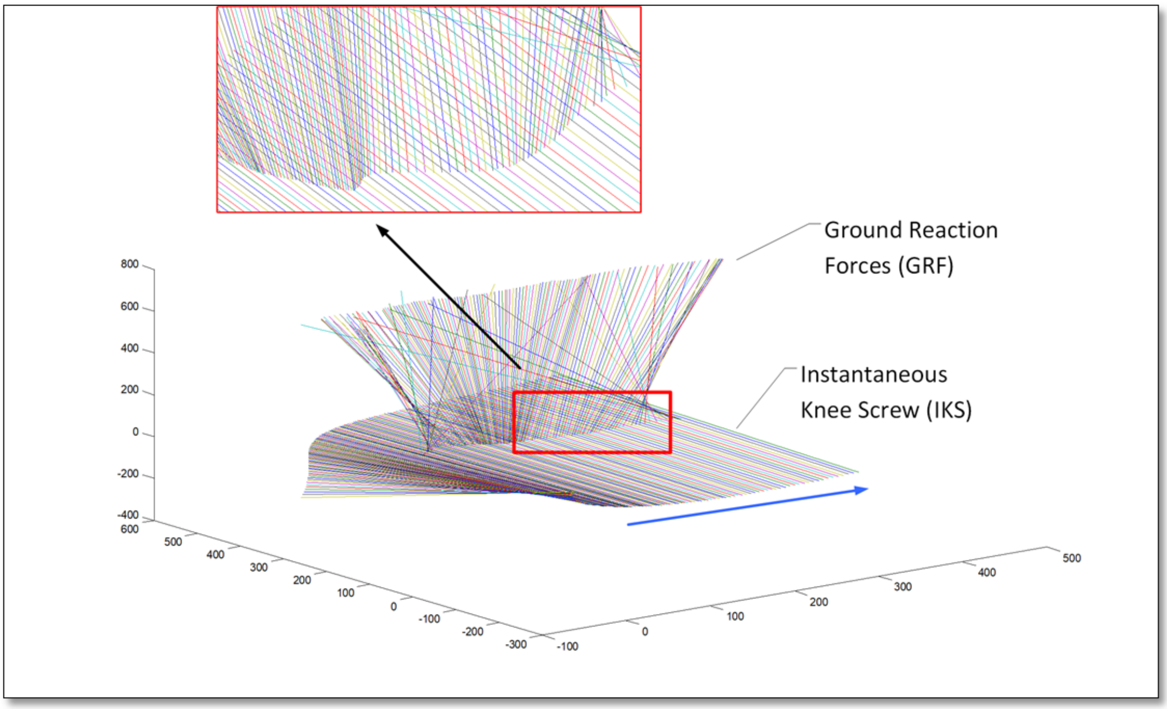


**Figure 4.** Direct perception and motor control during the stance phase of gait entrains the articulation of knee joint rotation with the touch pattern (GRF) of the foot. This explains how perceivers judiciously pick up the IKS as haptic information for perceiving affordances.

## DISCUSSION

In this study, we present the positive affordance-based design objective on graft placement while in continuous tension, rather than designing against the negative affordance by preventing impingement. For the ACL-patient to engage the IKS directly, clinicians have to measure the tunnel placement relative to the posture and behavior of the person being considered, making continuous graft tension possible. If the path of an ACL graft is so selected that it cuts the IKS of the self-tunning system of the knee (STSK) then the line becomes a member of the STSK, which ensures the isokinetic graft placement related to trans-tibial-femoral tunneling.

If a self-tuning system of the perceptual organ of the knee can be pre-stressed to get the same configuration as if external loads were applied, then this feature allows the pre-stress to be chosen to yield the same configuration in the swing phase (external forces are absent), as will be achieved in the stance phase where the external forces are present [15]. It has also been noted that preparedness is not only a reactive aspect of the movement apparatus, it also relates to anticipatory adjustments that predispose a system to behave in a particular way [16]. Bruner studied the “attainment of competence”. “In the growth of such competence in infants, three themes are central-intention, feedback and the patterns of action that mediate between them” [17]. Bruner’s description of an infant’s actions in capturing an object differed from earlier descriptions of reaching and grasping because he emphasized the intentional, unified character of the action. Bruner quoted Bernstein's model [18] for programming an action, one that emphasizes neither reflexes nor random responses but "future requirements" [6].

The Russian physiologist Bernstein [18] defined coordination as a problem of mastering the very many degrees of freedom (DOF) involved in the particular movement by reducing the number of independent variables to be controlled [19]. However, in order to reduce the number of musculoskeletal DOFs upon which the nervous system must operate, we have adopted the proposition that the nervous system controls muscle synergies, or groups of co-activated muscles, rather than individual muscles [20, 21]. Bernstein (1967) saw that this meant that actions must be planned at a very abstract level because it is impossible for the central nervous system to program all of these local, contextually varying, force-related interactions specifically and ahead of time. Indeed, once a decision to move has been made, the subsystems and components that actually produce the limb trajectory are softly assembled (to use a term introduced later by [22]) from whatever is available and best fits the task. This type of organization allows the system great flexibility to meet the demands of the task within a continually changing environment while maintaining a movement category suited to the goal in mind [23].

## CONCLUSION

It will greatly facilitate our further surgical design process to introduce how information is picked up, which will clearly exhibit the determinate character of the (S, T). It must thus be apparent the sensitivity of the knee to its disposition, IKS depends upon one parameter (S, T) family, and that consequently, the different position of IKS would form a single infinite series, known in linear geometry as a cylindroid proposed [11]. Then walkers must pick up IKS uniquely from the screw on the cylindroid, which is reciprocal to the GRF. This explains how perceivers judiciously pick up the IKS as haptic information for perceiving affordances. For S and T, must compound into a screw on IKS, whence walkers perceive affordances of the surface. It demonstrates that a unique combination of invariants, a compound invariant, is just another invariant [3].

Walkers explore the cylindroid (S, T), which contains these two screws. Since (S,T) are appropriated to two different body segments of the knee joint, no kinematic significance or meaning can be attached to the composition of the two twists on (S,T). If however, the two twists on (S,T), having the proper ratios of amplitudes, had been applied to a single rigid body, the displacement produced is one which could have been effected by a single twist about a single screw on the cylindroid (S,T). If this intermediate screw, the IKS, be given, the ratio of the amplitude of the twists on the given screw (S, T) is determined.

This study sought to offer a design method supporting knee reconstruction surgery, affording an approach for the user/surgeon/therapist. Thus the cylindroid must become a familiar conception with the students of the theory of affordance based design.

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