Hardness perception in visual motion  
—An experimental investigation in penetrating motion—

Tomohiro MASUDA*, Atsushi KIMURA*, Sho-ichi GOTO**, and Yuji WADA*
National Food Research Institute* and University of Tsukuba**

We investigated the influence of pre-penetration and penetration velocity changes (deceleration/constant velocity/acceleration) on visual hardness judgments. Participants were asked to judge, using an analog scale, the relative hardness of the penetrated objects compared to a standard pattern with no changes in acceleration. The results show that perceptual hardness was higher when the penetrating object decelerated during pre-penetration, or accelerated during penetration, but was lower when the velocity changed from acceleration to deceleration. Our findings reveal that the visual perception of hardness is influenced by velocity changes of the penetrating object during penetration. In addition, the current results imply that velocity change during pre-penetration, which is not directly related to actual penetration in a natural environment, is one factor determining the visual perception of texture.

**Key words:** motion perception, event perception, non-rigid motion

The act of piercing something is called "penetration". Motion during penetration varies depending on the material of the objects involved and the penetration depth. In other words, changes in the velocity of the penetration provide rich cues for determining the texture of the penetrated object.

Some researchers have reported that we perceive the various textures of objects based on visual motion. For example, when an object moving with a rapid change in velocity crosses a border between different colored background areas, observers perceive a change in texture of the area that the object passed (Levitt, 1962). Thus we expect that the texture of a penetrated object can be perceived from the visual velocity changes during a penetration event. Indeed, a change in velocity is proportional to the forces acting on the object.

In the present investigation we examined the effects of velocity change of a penetrating object on the perceived texture of the penetrated object. The first of two phases was pre-penetration: this ranged from the approach of a penetrating object to the object which was to be penetrated, to when the surface of the penetrated object was touched. The second phase was the penetration of the object. It can be assumed that: the velocity change in the first phase implied the strength of pressure for the penetration; and that the velocity change in the second phase implied the force of friction acting on the penetrating object.

**Methods**

**Participants.** Six healthy adults participated in the experiment (average age = 30.33 years, S.D. = 5.68). They all had normal or corrected-to-normal vision.

**Visual patterns.** The visual patterns were presented on a CRT monitor. In these patterns, a stick-like object (penetrating object) approached and pierced a fixed object (penetrated object, see Figure 1). We manipulated the velocity changes (deceleration, constant velocity, acceleration) of the penetrating object in two phases (pre-penetration and penetration), which were identical in duration (1.0 sec) and were presented sequentially without an interval. Thus, a total of nine visual patterns with varied velocity changes were generated. The patterns representing each condition were presented in random order.

**Procedure.** The head of each participant was fixed to a chin-rest approximately 114 cm from the CRT monitor and the visual patterns were observed binocularly in a dark room after a dark adaptation.

* National Food Research Institute, 2-1-12, Kannondai, Tsukuba, Ibaraki 305-8642
** University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573
e-mail: mastomo@affrc.go.jp
period of 10 min. Each visual stimulus was presented after the presentation of a standard pattern that had no velocity changes. Participants were allowed to observe the stimuli as often as they wished until they felt that they could rate the relative hardness of the penetrated object as compared to that of the standard pattern. They judged both the surface and interior hardness of each penetrated object. When compared to the standard pattern, the perceived hardness was rated by using a visual analog scale for hardness ranging from "much lower" to "much higher". Participants were allowed to check any point on the scale. Using a linear scale, "much higher" was assigned a value of 1 and "much lower" was assigned a value of -1, with 0 indicating the same hardness as the standard pattern.

**Results and Discussion**

Table 1 displays the mean ratings of the surface and internal hardness as compared to the standard pattern, and the results of the two-tailed t-tests. The abbreviations indicate the conditions of velocity change for pre-penetration and penetration (e.g., "acc-const" indicates acceleration during the pre-penetration phase and constant velocity during the penetration phase).

These results indicate that the surface hardness was significantly higher than zero under all pre-penetration deceleration conditions and all penetration acceleration conditions. The internal hardness was significantly higher than zero under the dec-acc and the acc-const conditions, and lower than zero under the acc-dec condition.

The results reveal that the surface of the penetrated object was perceived as harder when the penetrating object decelerated during pre-penetration or accelerated during penetration. The inside of the penetrated object was judged as less hard when the penetrating object went from acceleration to deceleration.

Generally, the motion of penetration into a hard surface is saliently slowed by the elastic deformation of the penetrated surface prior to fracture, after which the penetrating object begins to accelerate as it perforates the penetrated object. On the other hand the deceleration of the penetrating object, due to surface elastic deformation, is slight when the penetrated object has a soft surface. Taken together, the current results suggest that the visual perception of the texture of a penetrated object is achieved using naturally-occurring motion cues such as velocity change. In addition, the current results imply that pre-penetration velocity change, which is not directly related to actual penetration in a natural environment, is one determining factor in visual texture perception.

**References**