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Kinetic properties of arm and hand movements as useful indices for evaluating the dexterity of dentists

Part 1 – The transference of orthodontic attachments during a bonding procedure

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Introduction

Previously, the dexterity of dentists was evaluated by examining the ‘accuracy’ and ‘speed’, such as by using the tweezers test¹⁾. However, no significant differences were found between the performance skills which were recorded before and after the dental curriculum evaluated by the tweezers test²⁾. A haptic virtual reality system is now often used to evaluate and train individuals for the hand skills required for dental practice, using only prosthetics³⁾. However, the hand skills required for orthodontic practice have not been evaluated rationally and efficiently based on the motion dynamics theory.

The human body motion control system is known to be planned and achieved neurally so that the goal of movement is most efficiently achieved^{4)~8)}. In general, it has been confirmed that the smoothness of movement can be evaluated quantitatively^{9), 10)} by using the jerk-cost, which is a squared integration of the jerk (the change rate of the acceleration). For reaching arm movements toward a target, Flash and Hogan⁷⁾

focused on the motion control and simulated it mathematically using the minimum-jerk model. According to the theory of motion control, the minimization of the jerk cost of the body movement optimizes the smoothness of the movement. In addition, kinematic features, such as the phase duration, peak tangential velocity and the symmetrical properties of the velocity profile are known to be useful measures for evaluating the skillfulness of arm motions^{10)~12)}. The jerk cost decreases and the velocity profile is optimized and approaches a bell-type profile in accord with the improvement of the skillfulness and smoothness of the arm movement.

The optimal hand and arm movements are learned and memorized during clinical experience, that is, repeated practice. As a result, an unconscious and smooth movement can be acquired for repetitive tasks. However, in orthodontic practice, the dexterity has traditionally been evaluated by the treatment results¹³⁾, and little is known about the kinetic significance of improvements in clinical techniques which may be developed by clinical exercise. When considering the

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'hand skills' or 'dexterity' of practitioners, it would be reasonable to evaluate not only the treatment outcome, but also the operator's performance skills, i.e., the smoothness of their hand motion during clinical practice and the variance in the end phase of motion (the accuracy of placement of a bracket that will be bonded onto the teeth). Therefore, it is important to evaluate the hand skills of the operator using kinematic parameters by simulating the motions performed during orthodontic practice.

The present study consists of two parts. The purposes of Part 1 of the study were to examine the characteristics of the transfer trajectories of orthodontic attachments while they are carried onto a tooth surface with tweezers, and to examine whether more skilled arm movements in placing the attachments are achieved by Experienced subjects compared with Novice subjects. Part 2 of the study deals with the motion of each arm and wrist joint during the transfer of an orthodontic bracket with tweezers, and will be reported separately.

Subjects

The subjects consisted of 41 female adults who were divided into two groups: an Experienced Group (20 females who had completed the three-year university postgraduate program in orthodontics; mean age, 32 years, 6 months) and a Novice Group (21 females who had not completed or were not participating in the orthodontic postgraduate program; mean age, 27 years, 4 months). All subjects were right-handed and had normal eyesight.

Methods

Each subject was asked to transfer a metallic orthodontic attachment (Victory Series™ Miniature Metal Bracket System, 3M Unitek Co., MN, U.S.A.) with tweezers onto the midpoint of the facial axis (FA point)¹⁴⁾ of an acrylic maxillary right permanent incisor and a first premolar tooth of a phantom, respectively, under the following four kinds of conditions (Fig. 1) : Task1, transfer an attachment that was

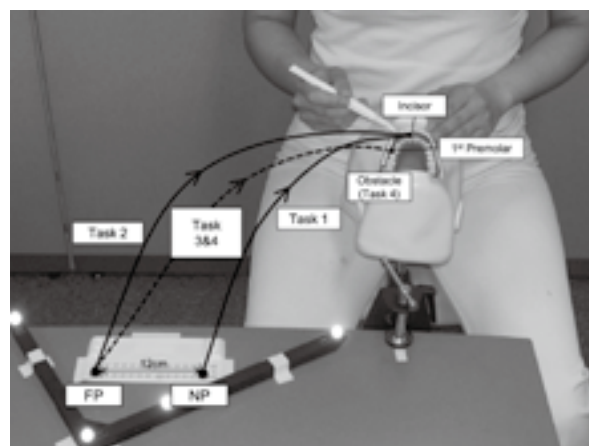


Figure 1. A schematic illustration of the hand movement trajectories that corresponded to the four tasks. The lateral point was located 11cm lateral to the medial point. Definitions of the Tasks: Task 1, Movement from the medial point (MP) to the upper central incisor; Task 2, Movement from the lateral point (LP) to the upper central incisor; Tasks 3 and 4, Movement from the LP to the upper first premolar. In Task 4, the operators placed the attachment without retracting the corners of the mouth.

placed on a tray which was located 22cm away from the phantom, which was referred to as the medial point (MP), to the maxillary central incisor; Task 2, transfer the attachment from a tray located 11cm lateral to the medial point, which was referred to as the lateral point (LP) to the maxillary right central incisor; Tasks 3 and 4, transfer the attachment from the LP to the FA point of the maxillary right first premolar with and without the operating retracting the corners of the mouth, respectively. Each task was performed seven times, with a one-minute interval between each task.

The three-dimensional trajectories of a light-weighted passive reflective marker with a diameter of 4mm adhered to the attachment were recorded at a sampling frequency of 100 Hz with a motion tracking system (OQUS Motion Capture Unit, Qualisys, Gothenburg, Sweden; Fig. 2). An L-shaped reference structure with four spherical markers was set on the desk, and was used for calibration. The mathematical function of the 30th order Fourier series was fit to the

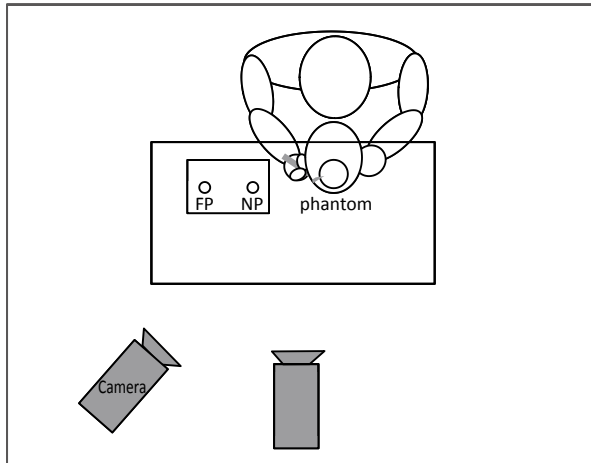


Figure 2. A view of the experimental set-up.

time serial data of the lateral, anteroposterior and vertical displacements of the attachment for each cycle. The functions $x(t)$, $y(t)$ and $z(t)$, which corresponded to the time series of the lateral (x), anteroposterior (y) and vertical (z) attachment displacement data, were obtained. The tangential velocity $TV(t)$ and tangential acceleration $TA(t)$ were calculated for each task.

The time points of the start and end of the tasks were determined for the three-dimensional displacement trajectory of the attachment to determine the entire phase duration. The peak tangential velocity was calculated in a velocity profile generated from the recorded data to define the acceleration and the deceleration phases (Fig. 3). The kinetic characteristics of the attachment transfer were quantified using

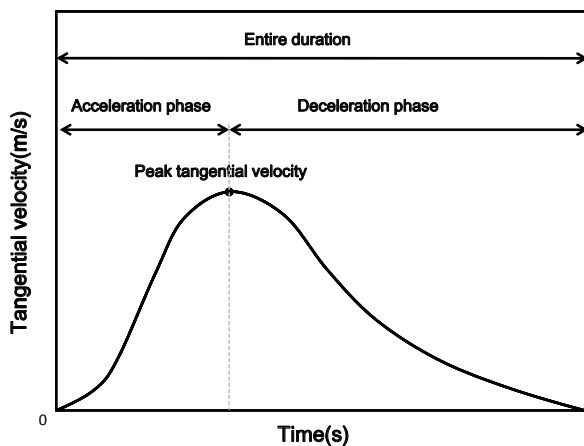


Figure 3. A schematic representation of the kinetic parameters.

normalized jerk-costs (NJC) for each phase, which were a time integral of the squared jerk (jerk-cost) normalized by the moving distances and durations.¹²⁾ A decrease in the NJC indicates an increase in the movement's smoothness.

The Mann-Whitney U test was used for the inter-task comparisons of the four tasks and the inter-group comparisons according to the kinematic variables for the arm movement. Values of $P < 0.05$ were considered to be statistically significant.

Results

Inter-task Comparisons (Table 1)

For the Novice Group

For Task 4, the mean durations were significantly longer ($P < 0.05$) and the mean NJCs were significantly greater ($P < 0.05$) than those calculated for the other three tasks in both the deceleration phase and the entire phase. The mean peak tangential velocity determined for Task 2 was significantly greater ($P = 0.003$) than that for Task 1. No significant differences were found ($P = 0.139$) for the mean peak tangential velocity between Task 3 and Task 4.

For the Experienced Group

The mean durations of both the entire and the deceleration phases that were calculated for Task 4 were significantly longer (both $P = 0.003$) than those for Task 3. There was no significant differences ($P = 0.328$) in the mean tangential velocity between Task 3 and Task 4.

The mean NJCs in the deceleration phase and the entire phase calculated for Task 4 were significantly greater ($P < 0.05$) than those for the other tasks.

Inter-group Comparisons (Table 2)

For Task 1, the mean duration of the deceleration phase for the Experienced Group was significantly shorter ($P = 0.033$) than that for the Novice Group. For Task 2, the mean durations of the deceleration phase and of the entire phase for the Experienced Group were significantly shorter ($P = 0.017$ and 0.015 , respec-

Table 1. The inter-task comparisons of the mean values calculated for the phase durations, as well as the peak tangential velocities and the normalized jerk-costs (NJC's).

Novice Group (n=21)

Task	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost		
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase
Task 1 (MP to incisor)	1.22	0.38	0.85	704.19	4482.36	28.01	1069.36
Task 2 (LP to incisor)	1.31	0.43	0.88	824.61	5165.28	43.70	1025.08
Task 3 (LP to premolar)	1.36	0.40	0.96	869.95	8098.31	37.40	2219.86
Task 4 (LP to premolar, without retracting the corners of the mouth)	1.55	0.45	1.12	754.03	15310.86	57.50	4297.82

Experienced Group (n=20)

Task	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost		
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase
Task 1 (MP to incisor)	1.15	0.37	0.76	768.13	4520.52	34.75	748.30
Task 2 (LP to incisor)	1.17	0.39	0.78	952.01	4428.43	37.68	815.42
Task 3 (LP to premolar)	1.22	0.40	0.83	865.72	5073.80	42.73	1151.51
Task 4 (LP to premolar, without retracting the corners of the mouth)	1.39	0.38	0.98	869.61	9521.46	38.44	2273.30

*: $p < .05$

tively) than those for the Novice Group. The peak tangential velocity for the Experienced Group was significantly faster ($P=0.036$) than that for the Novice Group.

For Task 3, the mean duration of the deceleration phase for the Experienced Group was significantly shorter ($P=0.037$) than that for the Novice Group. The mean NJCs in the deceleration phase and the entire phase calculated for the Experienced Group were significantly smaller ($P=0.018$ and 0.020 , respectively) than those for the Novice Group.

For Task 4, the mean durations of both the acceleration and the deceleration phases for the Experienced Group were significantly shorter ($P=0.024$ and 0.045 , respectively) than those for the Novice Group.

Discussion

There is an agreement among researchers that body movement is organized to achieve optimized movement^{4)~8)}. Specific kinetic parameters are known to be effective for evaluating the arm motion^{9)~12)}, as well as the jaw motion^{15), 16)}.

In the present study, the kinetic characteristics of transferring an orthodontic attachment onto the tooth surface with tweezers were found to be well explained by the peak tangential velocity, the phase duration and the normalized jerk-cost. From the results of the inter-task comparisons, both in the Experienced Group and the Novice Group, the mean peak tangential velocity for Task 2 was significantly faster than that for Task 1. In other words, the results showed that as the attachment movement distance increased, the peak velocity also increased. Significant prolongation of the phase duration and an increase of the NJCs were found for Task 4 compared with Task 3 in both subject groups. This is consistent with a previous finding¹⁷⁾ that the smoothness of motion is decreased and the movement time is prolonged when there is an obstacle in the movement path.

From the inter-group comparisons, a prolonged duration of the deceleration phase in the Novice Group was found for all tasks compared to the Experienced Group. In the present study, the task required was not a simple operation involving just moving an object between two points, but also necessitated an accuracy of positioning of less than ± 0.1

Table 2. The inter-group comparisons of the mean values calculated for the phase durations, as well as the peak tangential velocities and the normalized jerk-costs (NJC's).

Task 1								
Subject Group	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost			Variances (mm)
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase	
Novice Group (n=21)	1.22	0.38	0.85	704.19	4482.36	28.01	1069.36	1.08
Experienced Orthodontists Group (n=20)	1.15	0.37	0.76	768.13	4520.52	34.75	748.30	1.09
	ns	ns	*	ns	ns	ns	ns	ns
Task 2								
Subject Group	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost			Variances (mm)
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase	
Novice Group (n=21)	1.31	0.43	0.88	824.61	5165.28	43.70	1025.08	1.09
Experienced Orthodontists Group (n=20)	1.17	0.39	0.78	952.01	4428.43	37.68	815.42	1.04
	*	ns	*	*	ns	ns	ns	ns
Task 3								
Subject Group	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost			Variances (mm)
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase	
Novice Group (n=21)	1.36	0.40	0.96	869.95	8098.31	37.40	2219.86	1.26
Experienced Orthodontists Group (n=20)	1.22	0.40	0.83	865.72	5073.80	42.73	1151.51	1.20
	ns	ns	*	ns	*	ns	*	ns
Task 4								
Subject Group	Phase duration (s)			Peak Tangential velocity (mm/s)	Normalized jerk-cost			Variances (mm)
	Entire phase	Acceleration phase	Deceleration phase		Entire phase	Acceleration phase	Deceleration phase	
Novice Group (n=21)	1.55	0.45	1.12	754.03	15310.86	57.50	4297.82	1.25
Experienced Orthodontists Group (n=20)	1.39	0.38	0.98	869.61	9521.46	38.44	2273.30	1.26
	*	*	*	ns	ns	ns	ns	ns

* : $p < .05$; n.s. : Statistically not significant.

mm on the tooth surface at the end-point of the transferring motion. In general, it is known that motion which requires higher accuracy tends to have a decreased velocity^{18)~20)}.

Clinical experience can be referred to as the repeated practice of an operation. Repeating practice of a motor task decreases the movement time and improves the motion smoothness¹¹⁾. In the present study, the motion during Task 3 in the Experienced Group was significantly smoother, with durations shorter than those observed in the Novice Group. Since practitioners usually place an attachment onto the premolar while retracting the corners of the mouth, the motion in Task 3 is considered to be more

similar to that seen in the actual clinical practice than Task 4. Thus, the highly skillful movement observed in Task 3 for the Experienced Group was explained by the clinical experience of the participants.

An evidence-based training and evaluation system is needed for apprenticeship programs. The quantitative and objective evaluation of the dexterity using the kinematic parameters described in this study could be useful for dental education in orthodontic clinical practice.

Conclusions

The motion characteristics of placing orthodontic

attachments onto appropriate positions on maxillary teeth were found to be explained by the kinetic parameters. A more skillful placement of the orthodontic attachment was found for the Experienced Group compared to the Novice Group.

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