Disturbed Grip Function in Women with Rheumatoid Arthritis

BERIT DELLHAG, NASSER HOSSEINI, TOMAS BREMELL, and PÁLL E. INGVARSSON

ABSTRACT. ***Objective.*** Hand dysfunction is a frequent cause of disability in rheumatoid arthritis (RA). In patients with RA, we studied the precision grip-lift sequence in relation to pain, stiffness, and observer assessed hand function and their relation to patients' experience of clumsiness and tendency to drop objects.

Methods. Performance of the precision grip-lift sequence was studied in 23 women with RA and 7 age and sex matched controls. The results were correlated to self-estimation of pain and stiffness of hands and to observer assessed measurements of hand function.

Results. A prolongation of the preload and loading phases and of the acceleration part of the transition phase as well as a disturbance of the safety margin (SM) during precision grip-lift were noted. Patients with good hand function (low Grip Ability Test score; GAT) displayed normal or increased SM compared to the healthy controls, whereas patients with more pronounced disease exhibited a lower SM. Disturbances seen in the precision grip-lift performance were related to stiffness, range of motion, and GAT score. In RA patients with decreased hand function the SM was correlated to feeling of clumsiness, but did not explain the frequency of object dropping.

Conclusion. A disturbance in the precision grip-lift performance was noted in patients with RA. These grip performance changes need further investigation to determine possible mechanisms. (J Rheumatol 2001;28:2624–33)

Key Indexing Terms:
RHEUMATOID ARTHRITIS HAND FUNCTION PRECISION GRIP

Hand function is necessary for activities of daily life (ADL) and other functions[1-3]. The ability to use the hands effectively is dependent on anatomical integrity, mobility, muscle strength, sensation, coordination, and absence of pain[4-6]. Grip function has been studied in 25 different ADL tasks[4,7], leading to classification of 8 prehensile patterns. The Pulp pinch and the Lateral pinch were the most common grips, and represented nearly half of the grips performed with the dominant hand. In the Pulp pinch, described by Napier as the "precision grip,"[8] objects are held between the thumb and the index and/or the middle finger, and the fingertips constitute the contact surface. In the Lateral pinch, objects are held between the thumb and the radial side of the index finger.

The sequential and parallel integration of sensory and motor events during the precision grip-lift sequence has been studied in healthy adults[9-11]. When lifting an object using the precision grip, a series of smoothly coordinated movement phases are recorded. During preparation for the lift, a parallel increase in the isometric grip and load forces is elicited by the index finger and thumb. This grip-lift synergy develops in children at the age of about 1–2 years[12]. The adaptation of the motor output to the physical properties of the object, which develops later during the preschool years, relies on memory representations of weight and size of the object to be lifted, as well as the friction between the grip surface and the skin of the fingertips[9-11,13-15]. The capacity and versatility in executing manipulatory tasks are also dependent upon the sensory innervation of the glabrous skin area of the volar aspect of the hand[9]. When an object is held in the air, the balance (or ratio) between the grip force and the load force, elicited from the fingers, provides a relatively small safety margin to avoid dropping the object[16]. Hand function remains stable in healthy adults until the age of about 65 years, after which it slowly decreases[17]. With the precision grip-lift method, the first signs of decreased performance are seen at the age of about 50 years[18].

Rheumatoid arthritis (RA) is a progressive and chronic systemic disease. Extraarticular manifestations of RA are not uncommon, e.g., peripheral neuropathy and myo-

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pathy[19–22]. Hand dysfunction is a frequent cause of disability in RA[19,23]. Decreased joint mobility, with reduced grip strength and deformities, occurs at an early stage of disease[24,25]. We have found that joint mobility of fingers, grip strength, pain, and stiffness could only partially explain the deficits of grip function seen in RA[2,26]. RA patients often complain about "clumsiness" and of frequently dropping objects — "it only slips out of my hands." Our hypothesis was that these problems could be due to dysfunction in sensory motor integration and fine motor control.

We studied the different phases of the precision grip-lift sequence in patients with RA to determine whether these methods could explain the clumsiness experienced in RA and to compare the results to some clinical tests used to assess hand function in RA.

MATERIALS AND METHODS

Subjects. Twenty-three women with seropositive RA participated. The mean age was 46 ± 8.6 years (mean ± SD, range 29–59), with a mean disease duration of 7.3 ± 4.6 (range 1–15) years. As controls, 7 age matched healthy women were included, mean age 47.7 ± 9.9 (range 25–59) years.

Selection. Criteria for inclusion in the study: Swedish-speaking women < 60 years of age, with seropositive RA and a disease duration < 15 years. Exclusion criteria were additional diagnoses that could affect nerve and muscle function or a history of surgery in the dominant arm or hand.

A total of 116 women under age 60 with the diagnosis of RA visited the Department of Rheumatology, Sahlgrenska University Hospital, Göteborg, in January and February 1996. Thirty-eight fulfilled the criteria and were invited to participate, and 27 accepted. Four dropouts occurred among patients due to insufficient grip strength, making them unable to manipulate the "grip object" correctly.

The age distribution in the RA group was the determining factor for selecting the healthy controls. Two women in each age group 29–44 and 54–59 and 4 women in the age group 45–53 were sought. The control women were found among the staff of the clinic and represented different professions. Recordings from one control had to be excluded due to a temporary technical failure of the recording equipment.

Fifteen of the 23 patients with RA (65%) worked outside the home, 10 fulltime. One woman was unemployed and another worked on a voluntary basis. Four women were fully on the sick list and 2 women had a disablement pension.

Eighteen of 23 women with RA received disease modifying antirheumatic drugs (DMARD; sodium aurothiomalate and methotrexate). Thirteen patients used DMARD in combination with nonsteroidal antiinflammatory drugs (NSAID) and 4 with corticosteroids. Four patients used only NSAID, and one woman did not use drugs.

Procedures

1. Initial clinical examination and interview. (A) Visible anatomical deformities, i.e., ulnar deviation, subluxations, swan neck, and boutonniere deformities of the dominant hand, were noted. (B) Subjects were asked if they experienced clumsiness of their hands, starting after disease onset. (This question was answered either Yes or No). (C) Subjects were asked how often they had dropped objects during the past week. The responses were never (= 1); once (= 2); more often but not daily (= 3); once a day (= 4); and several times daily (= 5).

2. Self-assessed measures. (A) The estimated feeling of stiffness, in the dominant hand, was recorded on a 0–100 mm visual analog scale (VAS)[27], where the left endpoint was defined as "no stiffness" and the right endpoint as "maximal stiffness." (B) Pain (nonresisted motion) in the dominant hand was measured on a 0–100 mm VAS[27], with the 2 endpoints defined as "no pain" (left) and "maximal pain" (right), corresponding to how painful their fingers felt. (C) The self-estimated hand function (SEHF) in the dominant hand, defined as ability to perform the normally occurring daily hand activities, was estimated by the subjects on a 0–100 mm VAS[27]. The 2 endpoints were defined as "no function" (left) and "normal function" (right), and the distance from the left endpoint to the mark was recorded. An earlier test-retest study of self-estimated hand function in 11 RA patients with an interval of 5–7 days showed a correlation coefficient of 0.98 (B. Dellhag, unpublished data). The distance from the left endpoint to the mark was recorded for each of the 3 scales. (D) Patients assessed their abilities of daily living using the Swedish version of the Health Assessment Questionnaire (HAQ)[28,29].

3. Observer assessed measurements. (A) The Semmes-Weinstein monofilament test (SW)[30,31] was used to measure the cutaneous sensibility (sensory function) in the volar part of the tips of the thumb and the index finger of the dominant hand. The test set uses monofilaments representing different forces (grams) from "normal sensibility" to "diminished protective sensation." The filaments have a constant length with increasing diameters. Briefly, a nylon monofilament attached to a Lucite rod was applied perpendicularly to the skin until it became bowed, i.e., when the peak-force threshold was achieved. The SW test is a reproducible test of peripheral sensory nerve function[32]. (B) The Keitel Hand Function Index (HFI)[33] was used to measure the range of motion (ROM) in fingers and wrists. The HFI consists of the first 9 items of a total of 24 from the Keitel Function Test[34]. The Keitel Function Test measures upper and lower extremity function. Items 1–5 represent finger function and items 6–9 wrist function. Observed performance is graded from 0 (cannot perform) to 2 or 3 (perform without difficulty). The HFI gives a maximum possible score of 42 (21 on each hand). (C) Grip force in the dominant hand was measured (Newtons, N) with an electronic instrument, the Grippit® (Detector AB, Göteborg, Sweden)[35]. The grip handle for power grip was replaced by a narrower

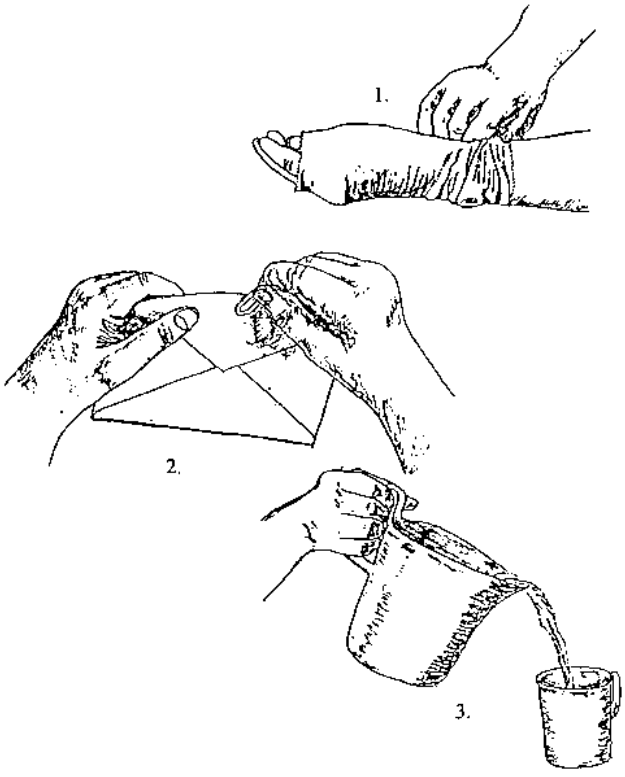

Figure 1. The Grip Ability Test. 1. Put a flex-grip stocking over the nondominant hand. 2. Put a paper clip on an envelope. 3. Pour water from a jug.

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handle with a width of 10 mm to quantify the pinch grip force. (D) The Grip Ability Test (GAT) was used to evaluate hand function. The GAT is a simple test for clinical evaluation of hand function in RA, a modified version of a grip function test based on studies of grips in different ADL[4]. The test consists of the 3 following practical tasks: put a flex-grip stocking over the nondominant hand, put a paper clip on an envelope, and pour water from a jug (Figure 1). The GAT score was the sum of the weighted time (seconds) for each task. A GAT score < 20 is considered normal. The GAT is valid, sensitive to change, and has high intraobserver (r = 0.99) and interobserver (r = 0.95) reliability[26]. A high GAT score indicates decreased hand function. In some of the analyses, patients were subdivided into 2 groups according to their GAT scores, i.e., 15 subjects with GAT scores within the normal range and 8 subjects with increased GAT scores. (E) The precision grip-lift sequence: The interaction between the horizontal grip (squeeze) force and the vertical lift (load) force was measured by grasping, lifting, and holding a specially designed object (Figure 2) between the thumb and the index finger. The object was modified from an earlier version[36] and has the shape of a square box (75 × 75 mm). Parallel grip surfaces (25 mm diameter), about 4 mm apart and covered with sandpaper (no. 100), were located on the top of the box. Force transducers (LuSense Sensors of the PS[3] family: thickness 0.49 mm, typical activation resistance range 1 MΩ > R_L > 2 kΩ for a pressure range of 0.5–100 N/cm^2) embedded in silicone were fastened to each side of the grip handle. The weight of the grip object was 620 g, which could represent many daily lifting tasks[37]. This grip object was carefully tested among the subjects and none of them expressed difficulties due to the weight of the object. A 12 bit A/D converter was used to digitize the data.

A separate series of tests were designed to estimate the minimum grip force needed to avoid letting the object slip between the fingers, the slip grip force (i.e., the grip force at slip). This was estimated by instructing the subjects to release the grip of the handle gradually during the hold phase, and let the object slip as smoothly as possible. Each recording consisted of 3–10 slips during 30 seconds, depending on the skill of the subject. Two files were recorded for each subject. The estimated final slip for each subject was the mean value of all lifts. The subjects performed repeated practice lifts and slips before the start of the tests, until they felt familiar with the grip object.

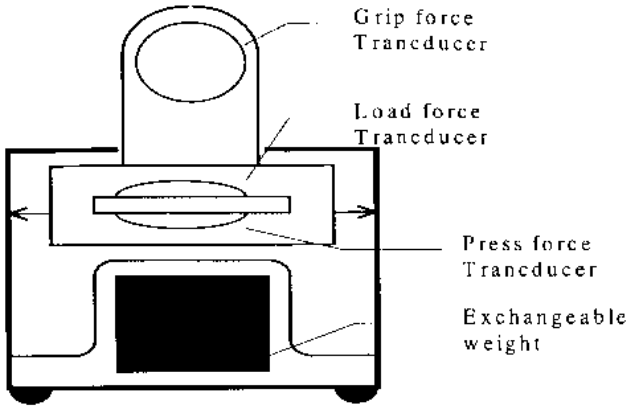
The precision grip-lift sequence was divided into the following phases: When both fingers had reached contact with the grip surfaces, only the grip (squeeze) forces increased during the preload phase, while the grip was established. Pinch grip was recommended, but if this turned out to be too difficult, the lateral pinch (the thumb and radial surface of middle or distal phalanx of the index finger) was allowed. During the loading phase the horizontal grip and vertical load forces increase in parallel until lift-off. This indicates the start of the transitional phase, i.e., when the object is elevated until it is held stationary in the air. In this phase the object accelerates upwards and the time between lift-off and the maximum vertical velocity of the object was defined as the acceleration phase[38]. Subjects were instructed to grip the object and lift it about 10 cm above the table surface and hold it stationary for up to 5 seconds in the static hold phase and then to gradually release the grip of the handle and let the object slip as smoothly as possible. The horizontal grip forces elicited from the index finger and thumb as well as the vertical load force were measured at 400 Hz during the grip-lift sequence. The movements were recorded by a Mac Reflex camera (Qualisys AB, Gothenburg, Sweden) at 50 Hz. To calculate the time for each phase, all the phases defined above were implemented in Matlab® environment.

Remeasurements of the precision grip-lift sequence and the GAT. After one year, when the data from the initial precision grip experiments had been analyzed, 12 of the 23 women with RA were evaluated by 2 methods of assessing the safety margin (see above). The GAT was also performed to confirm the preliminary results. The selection of the women was based on their earlier GAT results (the 4 patients with the lowest, intermediate, and highest GAT value, respectively). One dropout was noted. Eight of the retested 11 women with RA had undergone changes in their pharmacological treatment, i.e., changes of dose or drugs.

4. Laboratory tests. The laboratory measures of disease activity — C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR, mm/h) — were obtained immediately after each recording session from all patients.

Data analyses. The data analyses from the precision grip-lift sequence focused mainly on 2 aspects of the precision grip-lift: (1) the time coordination of the initial preload and loading phases of the lift, the acceleration part of the transition phase; and (2) the determination of the safety margin and slip ratio during the static (hold) phase of the lift.

The safety margin (SM) in precision grip has been defined[39,40] as the difference between slip ratio (i.e., the slip ratio is the ratio between grip force and load force at the point when the object begins to slip: slip start) and the static ratio (the mean value of the ratio between grip and load forces 0.2 s (t_0) after the load force peak, in the beginning of lifting, for the dura-



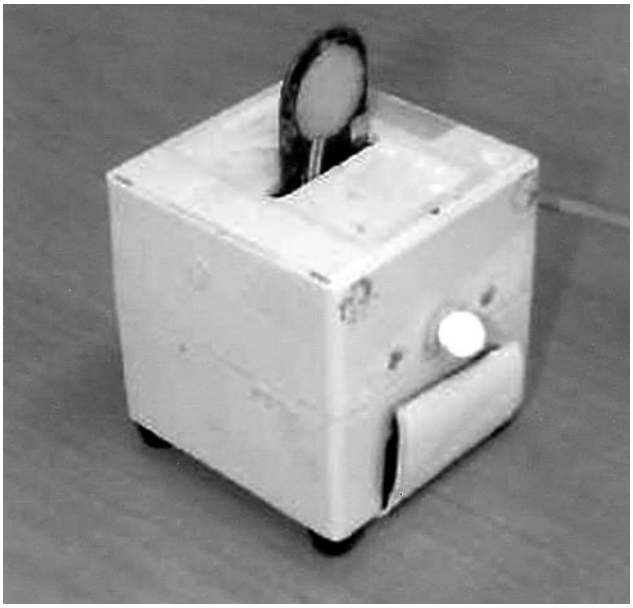


Figure 2. The measuring device used in the precision grip-lift.

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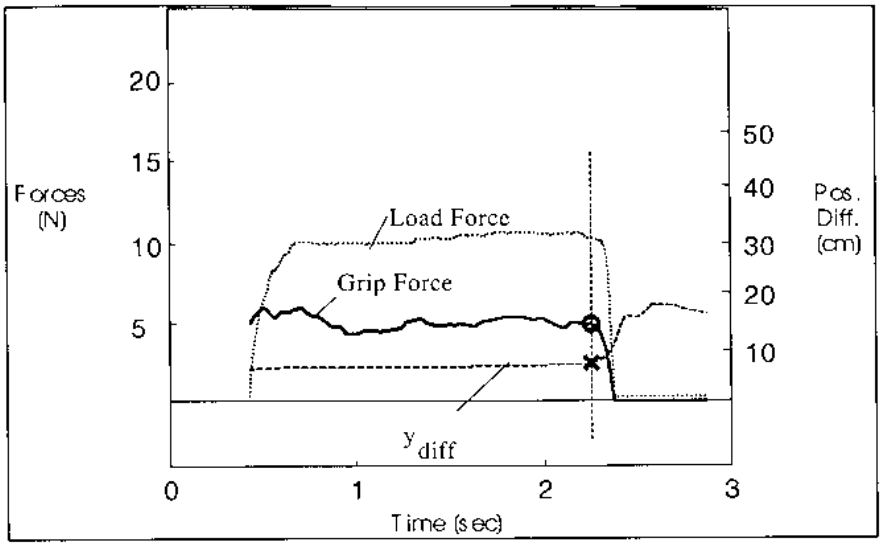

Figure 3. The moment of increasing difference in vertical position of the index finger and the object is detected and slip ratio is calculated as the ratio grip force/load force at this point.

tion of 0.5 s ($t_1 = t_0 + 0.5$), in the repeated lifts (Figure 3). The relative safety margin is defined as the percentage of the slip ratio:

$$\text{Slip ratio} = \left.\frac{\text{Grip force}}{\text{Load force}}\right| \text{Slip start}$$

$$\text{Static ratio} = \text{Mean}\left(\left.\frac{\text{Grip force}}{\text{Load force}}\right|_{t_0}^{t_1}\right)$$

$$\text{Relative safety margin} = \frac{\text{Static ratio} - \text{Slip ratio}}{\text{Slip ratio}}$$

The kinetic properties of the fingers and the object were used as an indicator of slip detection, i.e., as long as the object is held still between the fingers (not slipping), the difference between finger and object in vertical position is nearly constant. As the slip begins, an increased difference is detected by a specially designed algorithm, the slip detection algorithm[38,39].

The algorithm was implemented in Matlab® environment. A graphical user interface was created to set parameters and to present the results graphically as well as numerically.

Statistical methods. Due to the variability of data in the patient group as well as our use of several ordinal scales, nonparametric methods were used throughout. All data are presented as medians and interquartile range ($Q_3 - Q_1$). The Mann-Whitney U test[41] was used for analysis of differences between groups, and the Wilcoxon signed rank test for intragroup differences. Correlations between different variables were analyzed by Spearman rank correlation.

RESULTS

Median values, interquartile, and total range of self-assessed measures and test results are presented in Table 1.

Physical findings, self-reported complaints, and laboratory measures. At examination, obvious deformities were found in the dominant hand of 7 women with RA. The mean disease duration in these 7 women was 10 years (SD ± 3), range 6–15, with no relation between disease duration and occurrence of visible finger deformity.

The patients displayed rather mild disease, the HAQ disability index showing a median value of 0.88 (1.2–0.53) with a total range of 0–1.6, and ESR and CRP showing median values of 24.5 (40.5–10) and 22 (39–6), respectively.

Sixteen of the 23 patients with RA (70%) reported an increased clumsiness starting after disease onset. Twelve of these and 3 more patients (15 in all, or 65% of patients) reported unintentional dropping of objects during the past week; 3 "once a day," 8 "more often, but not every day," and 4 only "once" noted a feeling of clumsiness. This perceived clumsiness correlated to GAT (Table 2). This unintentional dropping was not related to visible hand deformities.

As expected, the self-reported measures pain and stiffness and the self-estimated hand function (SEHF) differed between groups. Estimated pain in the dominant hand was rather low, with a median value of 7 on the 100 mm VAS (Table 1), and only 2 women with RA estimated a hand pain more than 45. Five patients reported no pain at all.

Observer assessed measurements of hand function. Most of the observer assessed measurements — the range of motion (HFI), the Grip Ability Test (GAT), the power grip strength, and phase durations of the loading and acceleration phases of the precision grip-lift test — differed significantly between the women with RA and the controls. The pinch grip strength, the preload phase, and the safety margin (see below) of the precision grip-lift test, as well as cutaneous sensibility, did not differ between groups (Table 1). Of the observer assessed hand function tests, the GAT and the power grip strength both correlated to disease duration. The power grip strength and the HFI displayed a significant correlation to the ESR, while the pinch grip strength corre-

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Table 1. Median values (Q_3– Q_1) and total range for self-reported measures, clinical hand function tests, and variables in precision grip-lift sequence (preload, loading, and acceleration phases and safety margin) in 23 women with RA and 7 healthy female controls, and significant difference (p value) between the 2 groups. Observer assessed tests refer to dominant hand (Mann Whitney U test).

	RA, n = 23	Controls, n = 7	p
Pain, 0–100	7 (23.25–1) 0–90	0 (0–0) 0–0	0.0014
Stiffness, 0–100	19 (44–9) 0–53	0 (0–0) 0–3	0.0014
Self-estimated hand function	73 (93.5–50.23) 23–100	100 (100–100)	0.0003
Sensibility digiti I, g	0.17 (0.17-0.17) 0.07–0.41	0.17 (0.17–0.17) 0.17–0.41	NS
Sensibility digiti II, g	0.17 (0.17–0.07) 0.07–0.41	0.17 (0.17–0.07) 0.07–0.17	NS
Pinch grip strength, Newton	34 (44–24) 12–64	40 (68–36) 36–96	NS
Power grip strength	120 (156–76) 14–308	300 (351–235) 128–412	00.18
Hand function index	33 (38.75–18.5) 6–42	42 (42–39) 38–42	0.0029
Grip ability test, GAT, adjusted seconds	20.2 (21.18–17.1) 11–31.9	14.6 (15.8–12.9) 12–21.1	0.0080
Preload phase, ms	48.4 (68.4–32.2) 11.4–547.1	34.7 (46.3–29.0) 13.8–54.4	NS
Loading phase, ms	115.9 (160.6–80.9) 39.4–390.4	53.8 (77.3–36.2) 29.6–112.5	0.029
Acceleration phase, ms	335.1 (439.1–307.6) 251–649.4	301 (304.1–268.2) 252.2–305.2	0.025
Safety margin, %	110.9 (181.8–48.7) –13.3 to 526.9	117.0 (139.1–81.5) 36.8–287.8	NS
CRP	22 (39–6) 5–88		
ESR, mm/h	24.5 (40.5–10) 3– 83		

Table 2. Variables in precision grip-lift sequence, perceived clumsiness, and frequencies of dropping objects correlated to self-assessed measures and hand function tests in 23 women with RA (Spearman rank correlation tests, correlation coefficient corrected for ties).

	Perceived Clumsiness	Frequency of Dropped Object	Loading Phase	Acceleration Phase	Safety Margin
Pain	–0.349	0.065	0.233	0.197	–0.379
Stiffness	–0.392	–0.153	0.691**	0.195	0.291
Self-estimated hand function	0.119	0.357	–0.654**	–0.283	0.157
HFI, DH	0.340	–0.240	–0.539*	0.078	0.333
GAT	0.665**	0.347	0.392	0.626**	–0.652**
Power grip strength, DH	0.047	–0.213	–0.258	–0.098	0.412
Perceived clumsiness	—	0.336	0.193	0.273	–0.356
Frequency dropped object	0.336	—	–0.131	0.054	–0.272

*p < 0.05; **p < 0.01. HFI: Hand Function Index; GAT: Grip Ability Test; DH: dominant hand.

lated to neither disease duration nor ESR. No correlations were found between the 4 variables in the grip-lift sequence and age, disease duration, ESR, or CRP. These variable correlations may be due to the variable expression of disease, e.g., cases with severe disability in the early phases of RA. Also, ESR and CRP are rather crude expressions of disease activity[42,43].

The precision grip-lift sequence. When patients executed the precision grip-lift sequence, the isometric preparation for the lift was performed in one single bell shaped force pulse, indicating adequate preplanning of the lift by the motor system (Figure 4). Although some differences in maximum load and grip force rates were seen in the single cases that were depicted in this graph, no significant differences between groups were found, as the intragroup variation was larger than the intergroup variation. Thus the mean of maximal Load Force Rate was 61.63, 49.01, and 75.76 N/s for the less disabled patients, more disabled patients, and controls, respectively. The corresponding figures for the mean of maximal Grip Force Rate were 36.67, 39.87, and 41.70 N/s.

The following main differences between patients and controls were found during the precision grip-lift sequence: (1) A tardiness at the initiation of the lift, i.e., during the loading phase (see above); (2) a prolongation of the first (acceleration) part of the transition phase (see above); and (3) a disturbance of the safety margin.

Patients who displayed a deficient grip function (GAT) demonstrated a lengthening of the acceleration part of the transition phase (r = 0.626, p = 0.0041) (Table 2).

The duration of loading phase in the precision grip-lift sequence correlated significantly to estimated stiffness (r = 0.691, p = 0.0015) (Table 2).

No significant internal correlations were found between the preloading, loading, and acceleration phase durations and the safety margins (data not shown). This indicates that

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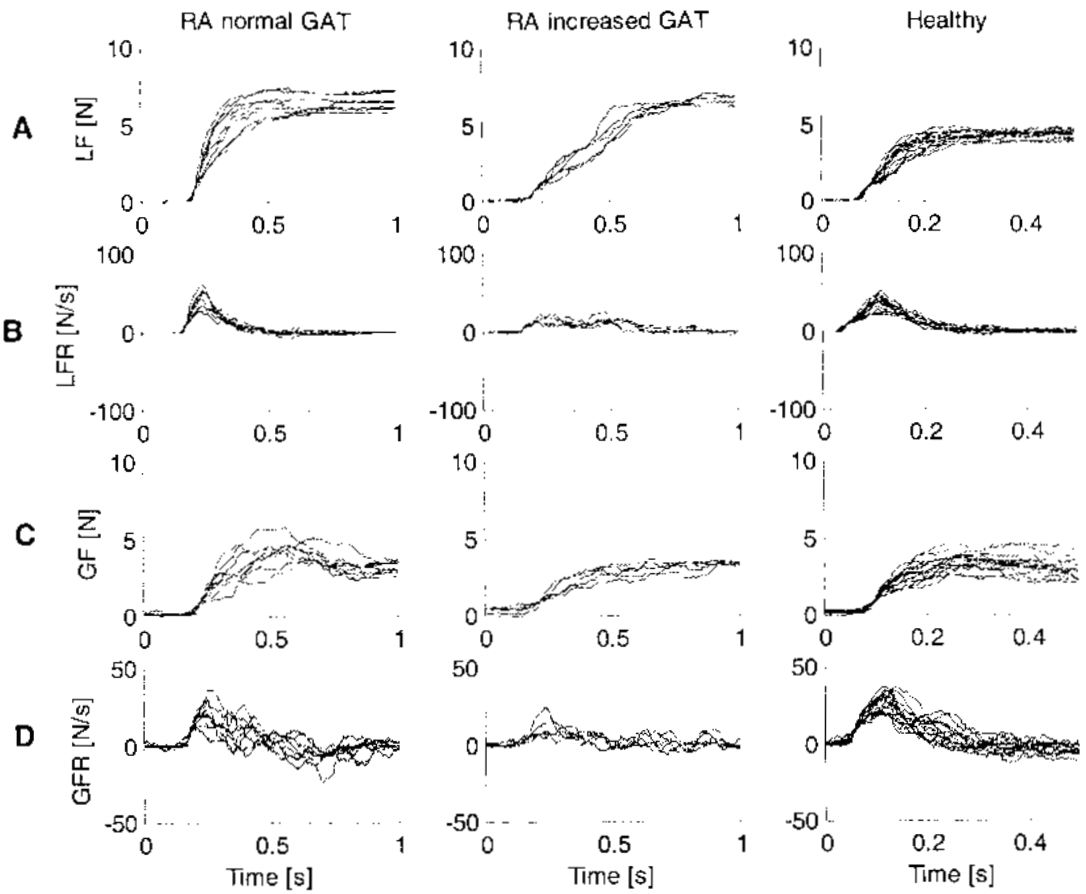

Figure 4. A. Load forces (LF), B. load force rates (LFR), C. grip forces (GF), D. grip force rates (GFR) for one healthy subject, for one RA patient with normal GAT score, and for one patient with increased GAT score.

prolonged phase durations in the early phases of the precision grip-lift sequence and the disturbances in the safety margin (see below) are not due to the same cause, but rather depend on different mechanisms that are not related to each other.

GAT showed a significant ($p = 0.0022$) relation to the safety margin (Table 2). Figure 5 illustrates a bimodal relationship between these 2 variables: patients with slightly decreased hand function (a low GAT value) displayed a tendency to increased safety margin compared to the controls. Decreasing safety margins were noted with increasing GAT values. In the most severely affected patients, the safety margin to slip even approached zero (or negative) values.

In Figure 6, the components of the safety margin, i.e., the load force at slip (slip LF, Figure 6A), grip force at slip (slip GF, Figure 6B), the static ratio calculated with these variables (Figure 6C), the slip ratio (Figure 6D), and the relative safety margin (Figure 6E) are illustrated. The subgroups of RA patients with normal and increased GAT scores again are depicted separately.

Comparing 15 women with RA presenting a "normal hand function" (GAT ≤ 20) to the group of 8 women with "decreased hand function" (GAT > 20), significant prolonged preload and acceleration phases ($p = 0.0051$) and a lower SM ($p = 0.0332$) were found in the women with decreased hand function (Table 3). Significantly more women ($p = 0.0332$) with "decreased hand function" reported a feeling of clumsiness. The GAT correlated significantly to the SM ($r = –0.652$, $p = 0.0022$). Apart from the different SM in the 2 RA groups, no significant differences were found between any of the groups in the variables illustrated in Figure 6.

Excluding the 2 women with extreme SM values (the one with a negative SM, the other with SM value close to zero) in the data analysis did not change the results except for a significant correlation between SM and perceived clumsiness correlation ($r = –0.487$, $p = 0.0294$).

Between the patients with "normal hand function" (by GAT) and controls no difference was seen in any variable in the grip-lift performance sequence.

After one year, when 11 of the RA patients were retested, no significant correlation between GAT and the safety margin was seen. The GAT score showed a median differ-

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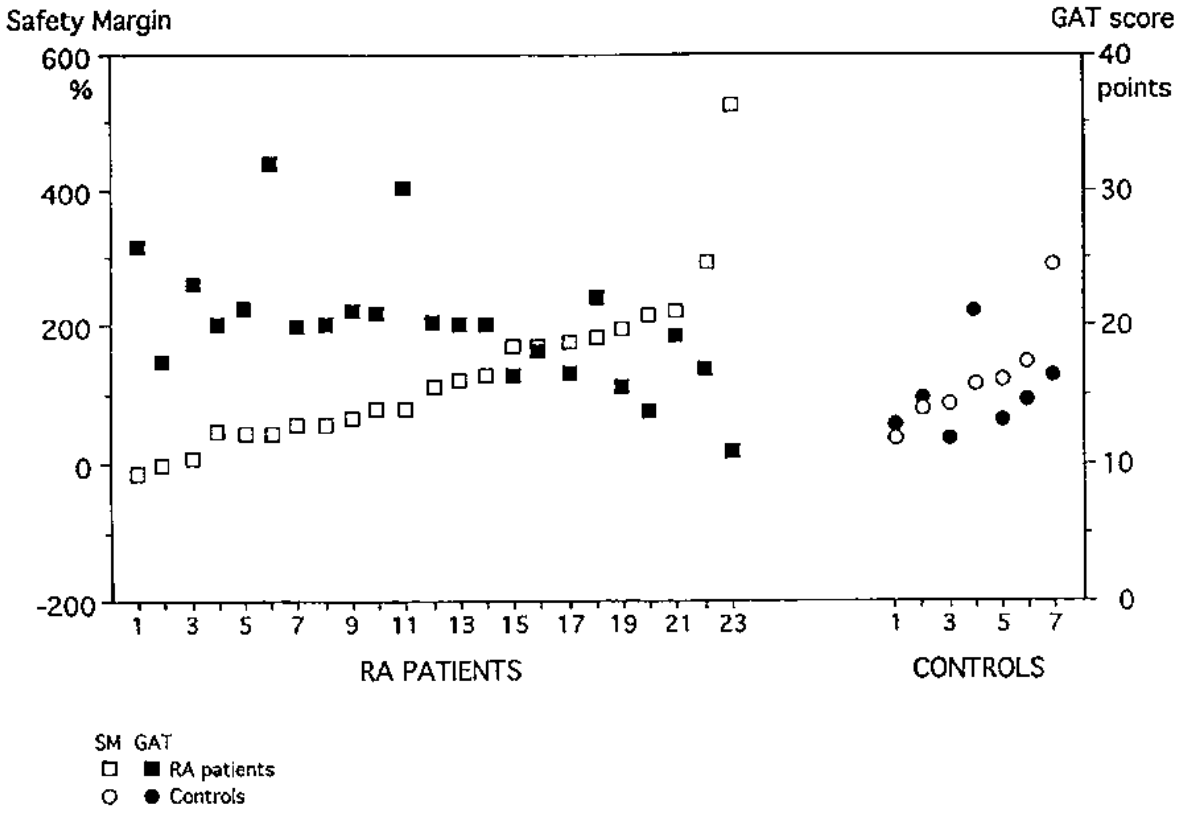

Figure 5. The bimodal relationship between GAT and the safety margin in women with RA and healthy controls. Data are presented for each individual.

ences value between the 2 times of measurements of –2.8 (–0.45 to –4.95) with maximum individual differences from –5 to +8.2 (total range at the first measurement 13.8 to 30.2, and at the second measurement 19 to 26). However, 8 of the 11 patients had changed their pharmacological treatment, i.e., drug and/or dose.

DISCUSSION

The main findings of the precision grip-lift sequence were prolongation of the loading phase and of the acceleration part of the transition phase of the precision lift compared with the controls. In women with RA with decreased hand function (by the GAT), a decreased safety margin and a prolonged preload phase were noted. The temporal and force variables used here are among the variables most commonly analyzed when grip-lift performance is studied.

Tardiness during the preload and loading phases. Tardiness during the establishment of the isometric grip and load forces during the loading phase, and a prolonged acceleration part of the transition phase of the precision grip

Table 3. Median values (Q_3–Q_1) and total range for the self-reported measures, clinical hand function tests, and variables in precision grip-lift sequence (preload, loading, and acceleration phases and safety margin) in 23 women with RA, 15 women presenting "normal" hand function (GAT score ≤ 20) and 8 women presenting decreased hand function (GAT score > 20). Observer assessed tests refer to dominant hand (Mann-Whitney U test).

	"Normal" Hand Function, n = 15	Decreased Hand Function, n = 8	p
Pain, 0–100	7 (12.8–1) 0–65	16.5 (40–1) 0–90	NS
Stiffness, 0–100	19 (29.3–4.3) 0–47	35 (44.5–15) 0–53	NS
Self-estimated hand function	87 (93.5–56.8) 23–100	62 (83.5–44.5)	NS
Pinch grip strength, Newton	42 (60–28) 12–64	26 (28–16) 16–40	0.0176
Power grip strength	136 (210–77) 14–308	120 (134–42) 28–156	NS
Preload phase, ms	39.1 (50.3–20.2) 11.4–95.3	76.3 (122.8–50.9) 47.2–547.1	0.0051
Loading phase, ms	93.8 (147.9–50.6) 39.4–271.5	131.2 (190.3–107.2) 106.4– 390.4	NS
Acceleration phase, ms	320.45 (362–296) 251–400	539.9 (597.9–384.5) 297.8–649.4	0.0051
Safety margin. %	169.5 (211–71.3) –0.9 to 526.9	55.6 (78.7–26.9) –13.3 to 196.7	0.0332

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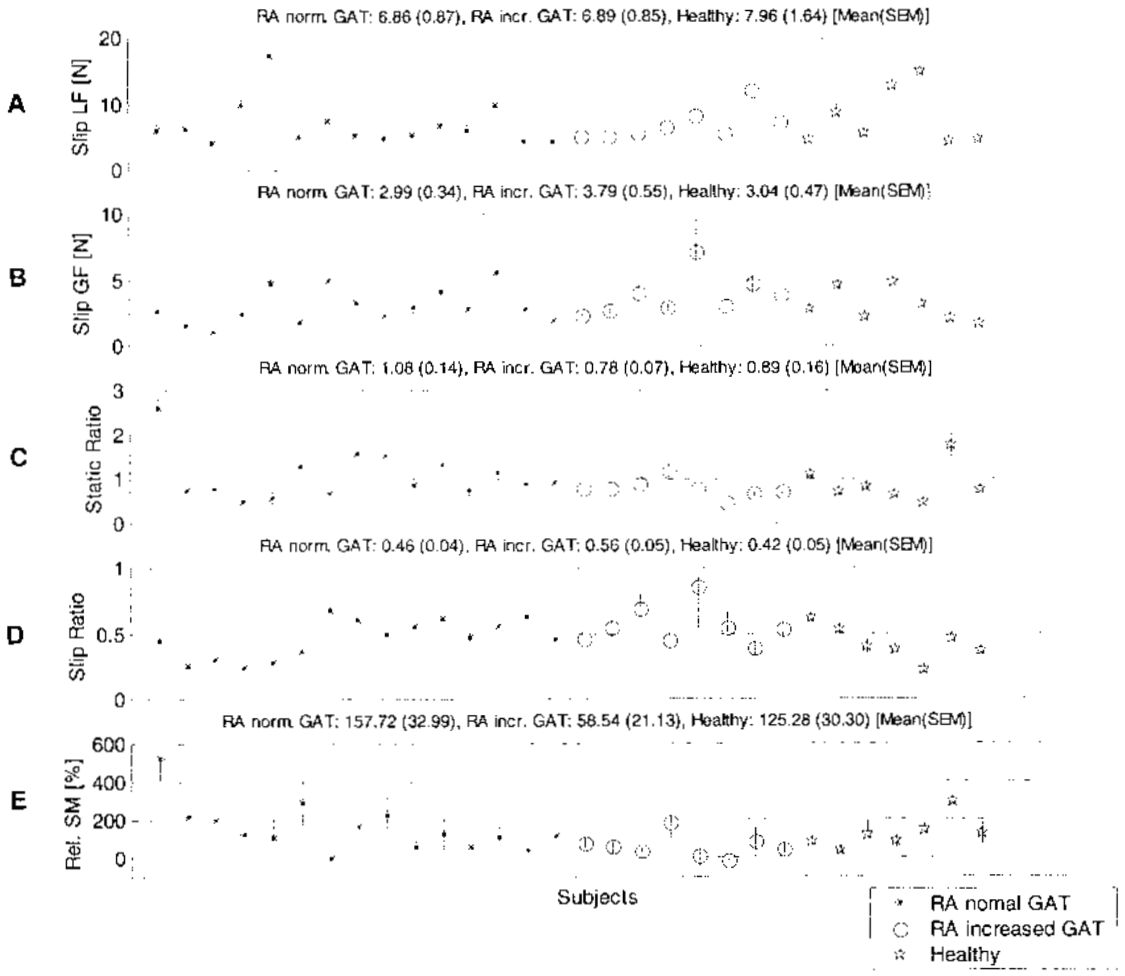

Figure 6. Mean values of (A) slip load forces, (B) slip grip forces, (C) static ratio, (D) slip ratio, (E) safety margin in patients with RA and healthy controls. Vertical lines indicate 95% confidence interval. In all figures show total mean value (Mean) and standard error of the mean (SEM). RA patients are divided into 2 subgroups with normal and increased GAT scores. Within each group, subjects are sorted after increasing GAT score.

sequence were expected findings. This may well have been due to mechanical factors that cause decreased dexterity and swiftness of the hand, e.g., effects secondary to inflammatory and destructive changes in the finger joints, tendons, and adjacent structures. One single force pulse during the grip and load force increase also indicates adequate anticipatory control of the force output required to lift the object (Figure 4).

The correlation of the loading phase duration to the patient's self-estimated stiffness (Table 2) further supports the notion that tardiness during the loading phase could be ascribed to mechanical factors. Previous findings from our group also indicate that grip strength (power grip) and stiffness estimate were the best predictors of variance of the patient's self-estimated hand function (SEHF)[2].

Changes of the safety margin. The SM results in the controls in this study are within the range for age groups similar to those described by Cole, *et al*[18]. In patients with good hand function, the SM was similar to or increased compared to the controls. However, RA patients displaying decreased GAT hand function also had a lower SM compared to patients with normal hand function. The lower SM, related to perceived clumsiness, may lead to slips and unintentional object dropping. The negative SM found in one patient with RA should consequently have led to dropping the test object, but it did not. This is hard to explain; possibly there was a measurement error or tilting of the object[44] at the slip moment could have induced this error. Any kind of tilting would nevertheless be a sign of inability to handle the test object correctly, despite a number of training trials before the measuring procedure started.

The changes in SM and GAT after one year may have been induced by variable disease expression and/or alterations of drug treatment. There was a considerable change of GAT score in these women with RA (–5 to +8.2) compared to a median GAT score variability of 0.95 (1.9 to –0.9) with individual maximum score differences from –3.5 to +3.6 in 14 healthy women that were measured at a mean

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interval of 18 weeks (range 1–52). Reliability of the GAT over time in this group was high ($r = 0.773$, $p = 0.0012$) (B. Dellhag, unpublished results). Most of the retested women with RA (73%) had undergone change in their pharmacological treatment. As well, disease activity could have changed considerably during that period. The well known statistical phenomenon of "deviation towards the mean" could also have influenced the results. Therefore we will repeat and extend these measurements and also the number of participants in a new study. Altogether, the changes after one year may show that disturbances in the grip-lift sequence are affected by drug therapy and disease activity.

The changes seen in the safety margin can hardly be explained by mechanical factors alone. As the demands upon the motor output system are moderate, including simple feedback mechanisms that do not need to be very fast, it seems less probable that diminished motor capacity is the explanation for this deficient control of the safety margin level. Findings from healthy subjects may suggest alternative mechanisms. The grip force during the static (hold) phase of a lift, and thus the safety margin, decreases gradually during prolonged holds of the test object. When a critical level is reached, small micro-slips result in immediate "upgrading," i.e., a sudden increase in and resetting of the grip force[45]. If a local anaesthetic is injected intradermally in the fingertips of healthy subjects, this balance is grossly disturbed, resulting in much higher grip forces during the static phase, and a manifold increase in the safety margin[16]. This indicates unequivocally that a neural sensorimotor control mechanism (where afferent sensory input regulates the motor output response of the fingers) maintains an adequate grip force by continuously adjusting the safety margin level. Thus a disturbance somewhere in the afferent loop of the sensorimotor control system seems to be a more probable reason for this disturbed SM control, at least in the most disabled RA patients. However, we found no differences between patients and controls with regard to cutaneous sensibility. Peripheral neuropathy may also be attributed to RA[19-22,46]. Could the possible disturbance be on a higher level (i.e., "upstream" from the cutaneous sensibility) of the sensory peripheral or even central nervous system? Interestingly, when Lanzillo, *et al* measured sensory and motor conduction velocities in RA patients without obvious subjective clinical symptoms or signs of neuropathy, they found subtle subclinical changes indicating a mixed sensorimotor neuropathy[46]. As an alternative explanation the changes in precision grip-lift performance and the GAT could be caused by pain, but this could not be verified in our study.

A lack of statistical difference of the safety margin between patients with RA and healthy controls was somewhat surprising. However, this seems to be due to a bimodal relation of SM values and GAT score in the RA patients: the least affected patients tended to have similar or even higher SM values than the controls, while lower SM values were found in patients with the highest GAT scores. This inverse relation between severity of disease and SM value is clear when the GAT scores and SM values for patients and controls are plotted (Figure 5).

In summary, although the number of subjects in this study is small, the results indicate a disturbed control of hand function in RA. Indeed, the rheumatic patient suffers symptoms of pain and stiffness that vary over time — even during a day. Mechanical factors may contribute to disturbances in these patients in smoothness, speed, and coordination, particularly during the early phases of the precision grip-lift sequence. However, the findings in this preliminary study also suggest alternative explanations; at least some aspects of the defective precision grip-lift performance, e.g., inadequate control of the safety margin, may be an expression of deficient integration and coordination of the sensorimotor system. Pain, or fear of pain, is a third possible explanation. The low safety margins tended to be reversible, as the most disabled patients had improved their performance when they were tested again about one year later.

Further investigations are needed to determine the underlying mechanisms that could explain the perceived clumsiness and tendency to drop objects by persons with RA.

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