Grasping Social Apathy: The Role of Reach-To-Grasp Action Kinematics for the Assessment of Social Apathy in Mild Neurocognitive Disorders

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Accepted 1 March 2021
Pre-press 1 April 2021

Abstract

\textbf{Background:} Social apathy, a reduction in initiative in proposing or engaging in social activities or interactions, is common in mild neurocognitive disorders (MND). Current apathy assessment relies on self-reports or clinical scales, but growing attention is devoted to defining more objective, measurable and non-invasive apathy proxies.

\textbf{Objective:} In the present study we investigated the interest of recording action kinematics in a social reach-to-grasp task for the assessment of social apathy.

\textbf{Methods:} Thirty participants took part in the study: 11 healthy controls (HC; 6 females, mean age = 68.3 ± 10.5 years) and 19 subjects with MND (13 females, mean age = 75.7 ± 6.3 years). Based on the Diagnostic Criteria for Apathy, MND subjects were classified as socially apathetic (A-MND, \( N = 9 \)) versus non-apathetic (NA-MND, \( N = 10 \)). SensRing, a ring-shaped wearable sensor, was placed on their index finger, and subjects were asked to reach and grasp a can to place it into a cup (individual condition) and pass it to a partner (social condition).

\textbf{Results:} In the reach-to-grasp phase of the action, HC and NA-MND showed different acceleration and velocity profiles in the social versus individual condition. No differences were found for A-MND.

\textbf{Conclusion:} Previous studies showed the interest of recording patients’ level of weekly motor activity for apathy assessment. Here we showed that a 10-min reach-to-grasp task may provide information to differentiate socially apathetic subjects with MND, thus providing a tool easily usable in the clinical practice. Future studies with a bigger sample are needed to better characterize these findings.

Keywords: Apathy, diagnosis, intention, motivation, motor activity, neurocognitive disorders, social behavior.

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\textbf{INTRODUCTION}

Apathy is a clinical syndrome characterized by a reduction in self-initiated, goal-directed activity, which is not driven by primary motor or sensory input. In mild neurocognitive disorders (MND), a reduction in social initiative and participation in social activities is common. Current apathy assessment relies on self-reports or clinical scales, but there is growing interest in defining more objective, measurable, and non-invasive apathy proxies.

\textbf{Methods:} Thirty participants took part in the study: 11 healthy controls (HC; 6 females, mean age = 68.3 ± 10.5 years) and 19 subjects with MND (13 females, mean age = 75.7 ± 6.3 years). Based on the Diagnostic Criteria for Apathy, MND subjects were classified as socially apathetic (A-MND, \( N = 9 \)) versus non-apathetic (NA-MND, \( N = 10 \)). SensRing, a ring-shaped wearable sensor, was placed on their index finger, and subjects were asked to reach and grasp a can to place it into a cup (individual condition) and pass it to a partner (social condition).

\textbf{Results:} In the reach-to-grasp phase of the action, HC and NA-MND showed different acceleration and velocity profiles in the social versus individual condition. No differences were found for A-MND.

\textbf{Conclusion:} Previous studies showed the interest of recording patients’ level of weekly motor activity for apathy assessment. Here we showed that a 10-min reach-to-grasp task may provide information to differentiate socially apathetic subjects with MND, thus providing a tool easily usable in the clinical practice. Future studies are needed to better characterize these findings.

Keywords: Apathy, diagnosis, intention, motivation, motor activity, neurocognitive disorders, social behavior.

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A preliminary study [23] suggested that recently recognized as a separate apathy dimension apathy—the loss of social motivation—has been only.

Critical, preliminary evidence suggests that interventions targeting apathy in people with MCI (through repetitive transcranial magnetic stimulation, rTMS) may be effective to improve the global cognitive functioning [16], thus suggesting that identifying apathy early in disease progression—and putting in place early treatment options—could offer new opportunities for dementia prevention [17].

Apathy is a multi-componential syndrome and can be manifested across different dimensions [1, 18]. These include: behavior (e.g., reduced level of activity at home or work, or difficulty to accomplish tasks spontaneously, without being prompted); cognition (e.g., reduced interests in leisure activities, news or personal health and wellbeing); emotions (e.g., reduced feelings and emotional expressions in response to self- or other-related events); and social interactions (e.g., reduced social relationships with family and friends, homebound). There is evidence that the various apathy domains can be differently impaired over the time-course of different diseases, such as PD, AD, and frontotemporal dementia [19, 20], and that they contribute differently to individual cognitive profiles [21]. While the behavioral, cognitive, and emotional dimensions of apathy had been previously identified and extensively investigated in clinical ND (see [6, 19] for reviews), social apathy—the loss of social motivation—has been only recently recognized as a separate apathy dimension [1, 18, 22]. A preliminary study [23] suggested that.

However, also these scales are intrinsically subjective, and depend on the quality of information available [31], thus making apathy assessment, including the assessment of self-awareness, which are common from cognitive impairment; questionnaires and interviews may suffer from subjectivity and bias. Indeed, self-report may be biased in patients with ND [28, 29]. The diagnostic criteria for apathy and the clinical scales administered by clinicians to patients and caregivers represent today the gold standard for apathy assessment [17].

Today, apathy assessment is mainly performed em-
Straulino and colleagues [48, 49] employed the very others, in social motivation, such people with PD. seems disrupted in patients with impairments, amongomatics based on the social versus individual context intentions. Second, this modulation of action kinematics based on the prior condition, thus suggesting a more careful approach in the social condition compared to the individual condition, thus providing additional elements for the assessment of the non-verbal aspects of social apathy in this population. The idea to employ this research protocol for social apathy assessment derived from three considerations. First, in healthy controls, action kinematics are sensitive to the social versus individual context in which the actions take place. Several previous studies showed that social intentions can influence action planning and execution: if we grasp an object to hand it to someone (social intention), the kinematics of the reach to grasp action is different from what observed when grasping the object to put it on a base (individual action), even if the object and its initial and final positions are exactly the same [43–47]. Specifically, both the kinematics of the reach-to-grasp phase (amplitude of maximum grip aperture and the speed at which the hands open, and movement smoothness) and the place phase (point of maximum trajectory height, peak velocity and time to peak velocity, movement smoothness) indicate a more careful approach in the social condition compared to the individual condition, thus suggesting a modulation of action kinematics based on the prior intentions. Second, this modulation of action kinematics based on the social versus individual context seems disrupted in patients with impairments, among others, in social motivation, such people with PD. Straulino and colleagues [48, 49] employed the very
kinematic action modulation may be impaired in apathetic MND subjects, resulting in fewer differences in action kinematics (movement velocity and acceleration/smoothness) between the individual and the social condition, especially in the reach-to-grasp phase, which is identical between the individual and the social conditions.

MATERIALS AND METHODS

Participants

Thirty participants took part in the study. These included 11 older healthy controls (HC; 6 females and 5 males, mean age = 68.3 ± 10.5 years) and 19 subjects diagnosed with MND based on the DSM-5 [57] (13 females and 6 males, mean age = 75.7 ± 6.3 years; see Table 1). All participants reported to be right-handed. Participants were recruited at the Memory Center (CMRR) of Nice University Hospitals (CHU of Nice, France) and at the CoBTeK research lab of the Université Côte d'Azur in the context of Marco-Sens multi-centric research protocol. Participants with MND were recruited in a 2-month timeframe among the patients followed at the Nice Memory Center. The study was proposed to all the patients meeting the study inclusion/exclusion criteria. All the patients that accepted to take part in the study were enrolled. Participants were not included if they had sensory or motor impairments interfering with the protocol completion, a score at the Mini-Mental State Examination (MMSE) < 22 [58], a Frontal Assessment Battery (FAB) score lower than 11 [59], and if they were diagnosed with major depression (and/or they were under antidepressant medication), PD, or other conditions associated to motor impairments. Healthy controls were recruited at the CMRR among the patients and subjects that came for a consultation sign of cognitive impairment, and the National Ethical Committee - Comité de Protection des Personnes - on 15/04/2019 – A00342-55. All participants were informed of the procedures and provided their informed consent before taking part in the study.

Clinical assessment

Based on the Diagnostic Criteria for Apathy [18], participants in the MND group were classified as ‘socially apathetic’ (A-MND; criterion “B3 – Social Interaction” present, N = 9) and ‘socially non-apathetic’ (NA-MND; criterion “B3 – Social Interaction” present, N = 9) and ‘socially non-apathetic’ (NA-MND; criterion “B3 – Social Interaction” present, N = 9). The presence of apathy was assessed based on the Diagnostic Criteria for Apathy, social dimension (B3; [18]).

<table>
<thead>
<tr>
<th>Variable</th>
<th>HC (n = 11)</th>
<th>NA-MND (n = 10)</th>
<th>A-MND (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>6 (54.5%)</td>
<td>7 (70.0%)</td>
<td>6 (66.7%)</td>
</tr>
<tr>
<td>Age (y), mean ± SD</td>
<td>68.3 ± 10.5</td>
<td>74.2 ± 7.2</td>
<td>77.4 ± 4.9</td>
</tr>
<tr>
<td>Level of education, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>1 (9.1%)</td>
<td>1 (10.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Secondary education</td>
<td>3 (27.3%)</td>
<td>5 (50.0%)</td>
<td>5 (55.6%)</td>
</tr>
<tr>
<td>Higher education</td>
<td>7 (63.6%)</td>
<td>4 (40.0%)</td>
<td>4 (44.4%)</td>
</tr>
<tr>
<td>MMSE, mean ± SD</td>
<td>29.3 ± 0.9</td>
<td>26.4 ± 2.9</td>
<td>25.6 ± 3.0</td>
</tr>
<tr>
<td>AMI – Total score</td>
<td>1.2 ± 0.4</td>
<td>1.0 ± 0.4</td>
<td>1.6 ± 0.4</td>
</tr>
<tr>
<td>AMI – Social Motivation</td>
<td>1.4 ± 0.7</td>
<td>1.1 ± 0.5</td>
<td>2.2 ± 0.6</td>
</tr>
<tr>
<td>AMI – Behavioral Activation</td>
<td>1.1 ± 0.6</td>
<td>0.7 ± 0.4</td>
<td>1.6 ± 0.9</td>
</tr>
<tr>
<td>AMI – Emotional Sensitivity</td>
<td>1.4 ± 0.6</td>
<td>1.2 ± 0.5</td>
<td>1.1 ± 0.5</td>
</tr>
</tbody>
</table>

MMSE, Mini-Mental State Examination; AMI, Apathy Motivation Index. aKruskal-Wallis test. bχ² test.
absent, N = 10). For all participants, the level of apathy was assessed through the AMI, an 18-item self-report scale developed to quantify apathy in the healthy population [22].

Instrument SensRing is a ring-shaped wearable device, worn on the proximal phalanx of the index finger, able to fully track the orientation and movement of the finger (Fig. 1). It is characterized by a 9-axes inertial measurement unit (IMU) LSM9DS1 (STMicroelectronics, Italy), which includes a 3D digital linear acceleration sensor (full scale: ±2/±4/±8/±16 g), a 3D digital angular rate sensor (full scale: ±245/±500/±2000 dps) and a 3D digital magnetic sensor (full scale: ±4/±8/±12/±16 gauss). It is based on an ARM®Cortex™-M3 32-bit STM32-F103 microcontroller (STMicroelectronics, Italy) which acquires, filters and stores data at a frequency of 50 Hz. Further details about the instrument can be found in [46, 47].

The reach-to-grasp task and procedures

The subjects were asked to wear SensRing on the proximal phalanx of the index finger of the right (dominant) hand. Participants were sitting in a quiet room, in front of a rectangular table with the hand in the starting position marked with a blue rectangle, 3 cm away from the edge of the table in a midsagittal position, 15 cm away from the midsection. A closed 150 ml drink can (diameter = 5 cm, height = 8.5 cm) was positioned on the table in front of the participant at 21 cm from the hand starting position along the midsagittal plane (object position marked with a yellow square). After 5 s of acquiring the baseline static position (with the wrist and little finger touching the table, hand palm facing the participant’s chest, fingers slightly bent and touching the thumb), a tone signaled to the participant to start the task. Participants were asked to reach and grasp an object in two conditions, adapted from [43]. In the Individual condition (IND), subjects had to reach the can, grasp it, and put inside a cup (diameter = 7 cm), placed on the table and located 28 cm at the right side with respect to the initial position of the can (position marked with a green rectangle). The experimenter (a 25-year-old female) seated to the right side of the table with her hands hidden below the table (see Fig. 1a). In the Social condition (SOC), subjects had to reach the can, grasp it, and pass it to a partner. The experimenter, who was also the action partner, seated to the right side of the table with the hand resting on the target position as in the IND condition (with fingers simulating a concave shape similar to the cup) ready to close the fingers when it reached the hand (see Fig. 1b). The experimenter’s hand was completely still until the object reached it. When the subject put the object in the hand, the experimenter closed their fingers to grasp it. The experimenter’s hand never moved from the target position, and her fingers closed only at the very end of the action, to simulate a natural ‘receiving the object’ action. In both conditions each action sequence was repeated 10 times, so each subject performed 20 trials, for a total duration of approximately 5 to 10 min. After each trial, the experimenter repositioned the can on its initial position. The order of administration of the two conditions was randomized across participants.
Inertial data acquired with SensRing were stored and offline processed using MATLAB R2018a (The MathWorks, Inc., Natick, MA, USA). Triaxial accelerations and triaxial angular velocities, provided by the accelerometer and gyroscope, were pre-processed with a fourth-order low-pass digital Butterworth filter using a 5 Hz cut-off frequency to erase high-frequency noise. Custom made algorithms were applied to extract characteristic times aimed to distinguish between the reaching phase (RG), from the beginning of the action to the grasping of the object, and a placing phase (PL) from the grasping of the object to reaching the final position. Precisely, angular rates around the dominant axis were used to divide the signal. For each trial, a set of kinematic parameters was obtained from acceleration and angular velocities of the SensRing (see). All the kinematic parameters were calculated both in the RG and the PL phases, except for the reaction time, and the amplitude and the time of maximum hand excursion that were measured during RG phase only. In total, 15 features were extracted for each trial (9 for the RG, 6 for the PL phase) (see). Some kinematic parameters were chosen because they may be relevant to investigate differences in the baseline motor performance between healthy controls and MND subjects, such as reaction time, execution times and movement duration [48, 60, 61]. Other parameters were selected because, as previously demonstrated, they are sensitive to variations in the action context (social versus individual), such as the amplitude of peak velocity during both the RG and the PL phases, with the corresponding time instant, the amplitude of maximum aperture of the hand during the reaching phase with its associated time instant [43, 45], and the movement smoothness and variability [46, 47] in the RG and PL phases.

RESULTS

Clinical and demographic characteristics

Clinical and demographic characteristics for apathetic MND (A-MND), non-apathetic MND (NA-MND), and HC are presented in Table 1. No differences in the three groups did not differ in terms of age (χ²(2) = 4.24, p = 0.120), gender (χ²(2) = 0.741), and education (χ²(4) = 2.699, p = 0.614), and significant differences were found concerning the global level of cognitive functioning, as revealed by the MMSE score (Kruskal-Wallis χ²(2) = 10.02, p = 0.007). Specifically, significant differences between subjects with MND (NA-MND, p = 0.020) were found, but not between subjects with NA-MND and A-MND (p = 0.628). No significant differences across groups were found concerning the global level of impairments in executive functions, as revealed by the FAB scores (Mann-Whitney U(2) = 40.5, p = 0.731). Significant differences across groups were found concerning the Social Motivation subscale score (χ²(2) = 13.15, p = 0.001). Specifically, as expected, A-MND showed lower scores compared to NA-MND (AMI – Social Motivation, p < 0.001; AMI – Total score, p = 0.020) and HC (AMI – Total score, p = 0.042). No significant differences were found between healthy scores were found between healthy controls and subjects with MND (NA-MND, p = 0.614) or between subjects with NA-MND and A-MND (p = 0.628). No significant differences in the AMPH (P < 0.05) were considered as statistically significant. Statistical analyses were performed using IBM SPSS version and MATLAB R2018a (The MathWorks, Inc., Natick, MA, USA) to compute post-hoc corrected tests and non-parametric analyses, data were submitted to two-way ANOVA, followed by LSD corrected tests and non-parametric partial correlations.
Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RmseJ</td>
<td>Root mean square of the rate of change of the acceleration: RG, PL</td>
<td></td>
<td>its value represents the smoothness of the movement (m/s³).</td>
</tr>
<tr>
<td>Skew</td>
<td>Skewness of the acceleration: it measures the asymmetry of the distribution. RG, PL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kurt</td>
<td>Kurtosis of the acceleration: it measures the shape of the tail of the distribution. RG, PL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Execution time spent to perform the movement (s). RG, PL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vpeak</td>
<td>Amplitude of peak velocity (m/s). RG, PL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T_vpeak</td>
<td>Time of peak velocity: it is the time instant corresponding to the peak velocity (s). RG, PL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>Reaction time: it is the elapsed time from the beep to starting the movement (s). RG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exc</td>
<td>Hand excursion: it is the amplitude of the maximum angular excursion RG</td>
<td></td>
<td>of the hand during the grasping of the object (deg).</td>
</tr>
<tr>
<td>T_exc</td>
<td>Time of maximum excursion: it is the time instant corresponding to the maximum hand excursion (s).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(AMI – Total score, \( p = 0.266 \); AMI – Social Motivation, \( p = 0.233 \)). For participants in the A-MND group, impairment in social interaction dimension (B3 in the Diagnostic Criteria for Apathy) was associated to impairment in the B1 dimension (Behavior/Cognition) in 4 participants, and with impairments in B2 dimension (Emotion) in 1 participant, for a total of 5 out of 9 participants that meet the full set of Diagnostic Criteria for Apathy [18].

Movement-related parameters

Intergroup analyses

In subjects with MND, motor impairments are much less common than in PD, and we excluded from the study participants with motor problems (see Participants section). However, there is evidence that advanced motor parameters reflecting motor planning and control may vary between healthy subjects and people with cognitive impairment, for instance in the context of dual tasks [56]. In order to investigate the existence of baseline differences in the motion-related parameters across groups in a reach-to-grasp task, we submitted each extracted parameter in two experimental conditions to separate between-subject analyses.

For the individual condition, the intergroup analysis revealed a significant effect of the group on the skewness of the reach-to-grasp phase (\( \text{Skew}, \chi^2(2) = 7.44, p = 0.024 \)). Specifically, skewness was significantly higher in the HC compared to A-MND participants, that get a negative value of skewness, indicating a wider variability for the acceleration vector for the movement with respect to the more symmetrical distribution shown by HC subjects. Comparisons between NA-MND and HC, and between NA-MND and A-MND were not statistically significant. A significant difference was also found in reaction times (\( \text{RT}, \chi^2(2) = 6.49, p = 0.039 \)), with A-MND participants significantly slower than HC (\( p = 0.041 \)). This is in line with the apathy literature suggesting that apathetic patients have often deficits in action initiation [2].

For the social condition, the only significant difference across groups was the time of peak velocity.
kinematics can be found between the individual and the social conditions [48, 49]. To explore the existence of differences in the kinematic parameterization depending on whether the action was performed with the intent of acting individually or socially, we compared the 15 kinematic parameters (listed in) in the individual versus social condition in each group in both the reach-to-grasp phase (which is identical in the two conditions) and the place phase (in which the experimenter’s hand and the cup pose slightly different action constraints). Correlations among the different kinematic variables are reported in the Supplementary Material (Supplementary Tables 1–4).

Reach-to-grasp phase

In the HC group, paired-sample Wilcoxon test showed significant differences between the individual and the social condition concerning the root mean square of the jerk, which is the rate of change of the acceleration vector ($RmseJ$, Wilcoxon Z = –2.22, $p = 0.026$), and the amplitude of peak velocity ($Vpeak$, Wilcoxon Z = –2.22, $p = 0.026$, see Fig. 3). Specifically, converging with previous findings, both acceleration and velocities were higher in the individual versus the social condition, suggesting a more careful approach when grasping the object to handle it to another person. No other significant differences were found. In the NA-MND group, a significant difference between conditions was found for the time of peak velocity ($Tvpeak$, Z = –2.30, $p = 0.022$), which was anticipated in the social versus the individual condition. This implies a longer deceleration phase for the social condition, thus a more careful action when passing the object into the partner’s hand. The only significant difference between the individual and social condition for A-MND was reaction time ($RT$, Z = –2.38, $p = 0.017$), which was longer in the individual versus the social condition.

Place phase

In the HC group, significant differences were found on the rate of change of the acceleration vector ($RmseJ$, Z = –2.76, $p = 0.006$) and the kurtosis ($Kurt$, Z = –2.85, $p = 0.004$), as well as on peak velocity ($Vpeak$, Z = –2.93, $p = 0.003$; see Fig. 4). Thus, similarly to the reach-to-grasp phase, both acceleration and velocity were higher in the individual condition compared to the social condition.
suggested a more careful approach when handing the object to another person. However, the total execution time was longer in the individual compared to the social condition ($T, Z = -2.31, \rho = 0.021$). This is most probably due to the fact that the object final position (the cup) required a more precise gesture for object positioning compared to passing the object to the partner, who closed the hand to grasp the object when it touched her hand. Similar results for acceleration and velocity where found for NA-MND participants, showing higher rate of change of the acceleration vector ($RmseJ, Z = -2.70, \rho = 0.007$), kurtosis ($Kurt, Z = -2.60, \rho = 0.009$) and peak velocity ($V_{peak}, Z = -2.80, \rho = 0.005$) in the individual compared to the social condition. In the place phase, significant differences on the same parameters were also found for A-MND participants, who showed a higher rate of change of the acceleration vector ($RmseJ, Z = -2.07, \rho = 0.038$), kurtosis ($Kurt, Z = -2.31, \rho = 0.021$) and peak velocity ($V_{peak}, Z = -2.55, \rho = 0.011$) in the individual compared to the social condition. Intergroup analyses suggested that the mean differences between individual and social condition regarding the amplitude of peak velocity were significantly different across groups ($\chi^2(2) = 10.56, \rho = 0.005$). Specifically, differences in peak velocity between conditions were significantly bigger for HC ($\rho = 0.003$) and NA-MND ($\rho = 0.008$) compared to A-MND. No significant difference in the magnitude of any acceleration parameter across groups was found (all $\rho s > 0.05$).

**DISCUSSION**

Social apathy, a reduction in initiating or engaging in social activities or interactions, is very common in people with ND [23], and few clinical scales exist so far to assess this component [22, 62]. It is thus important to develop rapid, objective assessment tools for clinical practice to complement the evaluation. In the present study, we showed measuring action kinematics during a reach-to-grasp social task to provide insights into non-verbal aspects of social apathy in MND. Participants were asked to grasp a drink can to put it in a cup (individual condition) or pass it to a partner (social condition) [43]. Action kinematics were measured during the reach-to-grasp and the place phases with wearable devices [46, 47]. Prior social intentions condition we perform actions: when grasping an object to pass it to another person, the action kinematics are different from those observed when grasping an object to put it in a container [43]. Converging with previous findings [48] and our hypotheses, the results of intra-group analyses suggested that MND subjects differentiated, at the kinematic level, individual from social reach-to-grasp actions both in the ‘reach-to-grasp phase’, and in the ‘place phase’. Specifically, in the reach-to-grasp phase, people with NA-MND showed a more careful approach, suggesting a more careful approach when handing the object to another person. This is most probably due to the fact that the object final position (the cup) required a more precise gesture for object positioning compared to passing the object to the partner, who closed the hand to grasp the object when it touched her hand. Similar results for acceleration and velocity were found for NA-MND participants, showing higher rate of change of the acceleration vector ($RmseJ, Z = -2.70, \rho = 0.007$), kurtosis ($Kurt, Z = -2.60, \rho = 0.009$) and peak velocity ($V_{peak}, Z = -2.80, \rho = 0.005$) in the individual compared to the social condition. In the place phase, significant differences on the same parameters were also found for A-MND participants, who showed a higher rate of change of the acceleration vector ($RmseJ, Z = -2.07, \rho = 0.038$), kurtosis ($Kurt, Z = -2.31, \rho = 0.021$) and peak velocity ($V_{peak}, Z = -2.55, \rho = 0.011$) in the individual compared to the social condition. Intergroup analyses suggested that the mean differences between individual and social condition regarding the amplitude of peak velocity were significantly different across groups ($\chi^2(2) = 10.56, \rho = 0.005$). Specifically, differences in peak velocity between conditions were significantly bigger for HC ($\rho = 0.003$) and NA-MND ($\rho = 0.008$) compared to A-MND. No significant difference in the magnitude of any acceleration parameter across groups was found (all $\rho s > 0.05$).
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It is hard to disentangle the roles of apathy and basic motor impairment in PD patients. Indeed, PD patients in the ‘off’ l-Dopa medication state were found to be unable to kinematically differentiate between individual and social conditions [48, 49]. Given that PD patients show motor impairments and apathy, and that both symptoms are sensitive to l-Dopa medication, in PD patients it is hard to disentangle the roles of apathy and basic motor impairment.

However, as participants in the HC, NA-MND, and A-MND groups were balanced in terms of demographic characteristics (age, sex, and education), our findings cannot be completely explained by age-related changes in motor planning and control. Similarly, employing the SensRing system, parameters linked to the amplitude of the peak acceleration and the smoothness of the movement may be particularly relevant to detect the presence of social apathy symptoms in a similar degree compared to HC and NA-MND. No main differences were found for action duration, indicating sharper movements with higher variability in acceleration than in HC and NA-MND. No main differences were found for action duration, indicating sharper movements with more variability in acceleration than in HC and NA-MND. The only significant difference between the individual and social condition for A-MND was the reaction time, which was longer in the individual versus social condition. This suggests that people with social apathy took longer to initiate the action in the individual condition, which could be possibly due to higher demands in action control in the object positioning, requiring a more careful action planning before action initiation.

Significant differences between the individual and social conditions were observed for A-MND in the ‘place’ phase, with lower velocity and acceleration profiles in the social compared to the individual condition. These differences were also found in HC and NA-MND; however, differences in peak velocity between the individual and social condition were significantly bigger in HC compared to A-MND, suggesting that action modulation based on social intentions in the place phase, even if present in A-MND, was smaller than in HC. The reduced modulation of action kinematics in A-MND subjects converges with results collected using the same experimental paradigm in PD patients. Indeed, PD patients in the ‘off’ l-Dopa medication state were found to be unable to kinematically differentiate between individual and social conditions [48, 49]. Given that PD patients show motor impairments and apathy, and that both symptoms are sensitive to l-Dopa medication, in PD patients it is hard to disentangle the roles of apathy and basic motor impairment.

There is evidence that age-related changes in global cognitive functioning (as NA-MND and A-MND participants had a similar impairment in global cognition) as well as NA-MND and A-MND participants showed a similar degree of social apathy as previously studied [2]. Similarly, employing the SensRing system, parameters linked to the amplitude of the peak velocity and acceleration profiles in the reach-to-grasp phase, indicating sharper movements with higher variability in acceleration than in HC and NA-MND. No main differences were found for action duration, indicating sharper movements with more variability in acceleration than in HC and NA-MND. The only significant difference between the individual and social condition for A-MND was the reaction time, which was longer in the individual versus social condition. This suggests that people with social apathy took longer to initiate the action in the individual condition, which could be possibly due to higher demands in action control in the object positioning, requiring a more careful action planning before action initiation. Significant differences between the individual and social conditions were observed for A-MND in the ‘place’ phase, with lower velocity and acceleration profiles in the social compared to the individual condition. These differences were also found in HC and NA-MND; however, differences in peak velocity between the individual and social condition were significantly bigger in HC compared to A-MND, suggesting that action modulation based on social intentions in the place phase, even if present in A-MND, was smaller than in HC. The reduced modulation of action kinematics in A-MND subjects converges with results collected using the same experimental paradigm in PD patients. Indeed, PD patients in the ‘off’ l-Dopa medication state were found to be unable to kinematically differentiate between individual and social conditions [48, 49]. Given that PD patients show motor impairments and apathy, and that both symptoms are sensitive to l-Dopa medication, in PD patients it is hard to disentangle the roles of apathy and basic motor impairment.
and more important is the small sample. It is possible that, for instance, including a bigger number of apathetic participants, more differences between the individual and the social conditions would have been found. Furthermore, a bigger sample would have allowed analyzing correlations between apathy scales and kinematic parameters, and to analyze simultaneously intra-group and inter-group effects, as well as their interactions, thus allowing to significantly reduce Type I errors. Future studies could use the present results to estimate the expected effect size and compute a power analysis to estimate the optimal sample size. Second, the wearable sensor we employed (SensRing), positioned on the index finger, allowed us to collect only data concerning angular acceleration and velocity of the hand. However, it did not allow to collect precise data on the finger movements (such as the amplitude of the maximum grip aperture), and spatial trajectories (such as the maximum height of the wrist trajectory from the working surface, or the length of the wrist pathway), that were found to be sensitive to social intentions in previous studies [43, 48, 64]. Future studies should investigate the interest of combining SensRing with other non-invasive sensors, such as RGBD cameras, to integrate position related data in the analyses. Third, despite trying to make the individual and the social conditions as similar as possible, they slightly differed concerning the precision required for the object positioning (in the cup versus the hand). In the next studies, it would be important to make the two conditions even more comparable, for instance by employing a larger concave base (replacing cup) and a lighter object that can be put on the hand palm without falling. Finally, precisely assessing participants’ baseline motor ability may help to disentangle the effects of apathy from basic motor skills, and to explore their relationships. Indeed, even if participants with

future studies with bigger samples, it would be interesting to analyze simultaneously the three apathy dimensions, to understand the role of the social, cognitive/behavioral, and emotional dimensions in action kinematics. Furthermore, in ND, apathy can be linked to other neuropsychiatric symptoms, such as depression, anhedonia, and fatigue [6]. It would be interesting to investigate the relationships between all these symptoms and modulation of social action kinematics in a reach-to-grasp protocol. Previous findings suggest that social apathy relates to the probability to engage in prosocial behaviors, with individuals less socially apathetic being more prone to make efforts to benefit the other [27, 66]. It would be interesting to investigate whether reduced social apathy and modulation of social action kinematics are related to prosocial behaviors in people with ND, employing effort-based tasks [27, 67]. Finally, it would be interesting to create more contexts in which action kinematics are combined with other non-invasive objective measures, such as estimated voice analysis during verbal exchanges, to capture different, complementary aspects of social apathy.

CONCLUSIONS

When reaching an object to prepare a social action (passing) versus an individual action (placing), healthy subjects, including elderly people, modulate action kinematics according to the goal of the action sequence: despite the object to be grasped is exactly the same and in the same position (as indexed by the FAB [59]), the reduced social apathy and reduced modulation of social action kinematics are linked to reduced prosocial behaviors in people with MND, for instance modulating voice analysis during verbal exchanges—to capture different, complementary aspects of social apathy.
difficulties in motor planning and control, resulting in impairments in action chains (observable, for instance, in reach-to-grasp sequences [74]) may contribute to explain deficits in interpersonal synchrony and intention understanding [75, 76], thus playing a role in explaining autism abnormalities in social interactions. Whether the link between social action modulation and social apathy is bidirectional or not, if the results of the present study are confirmed in a bigger sample, action kinematic modulation may be a non-invasive, simple and fast way to complement the classical clinical assessment with quantifiable and objective data.

ACKNOWLEDGMENTS

This work has been supported by the French government, through the UCA JEDI Investments in the Future project managed by the National Research Agency (ANR) with the reference number ANR-15-IDEX-01 in the context of ‘MNC3’ project. This work was also supported by the following grants: ‘APAMOT’ grant from the FRIS (Fédération de Recherche Interventions en Santé) of the Université Côte d’Azur, Nice, France; ‘SI-ROBOTICS – “Healthy and active ageing through Social ROBOTICS” (European Union – FESR o FSE, PON Research and Innovation 2014-2020 Project ARS01_01120); and CloudIA project (Regione Toscana, POR CREO FESR 2014-2020, CUP 165.24052017.11200015). Additional supports came from the Association IA, and the JL Noisiez Foundation. Thanks to Raphael Zory, Xavier Corveley, and Alexandra Plonka for their support in the study development and data collection.

Authors’ disclosures available online (https://www.j-alz.com/manuscript-disclosures/20-0966r3).

Brain 124, 96-102.


